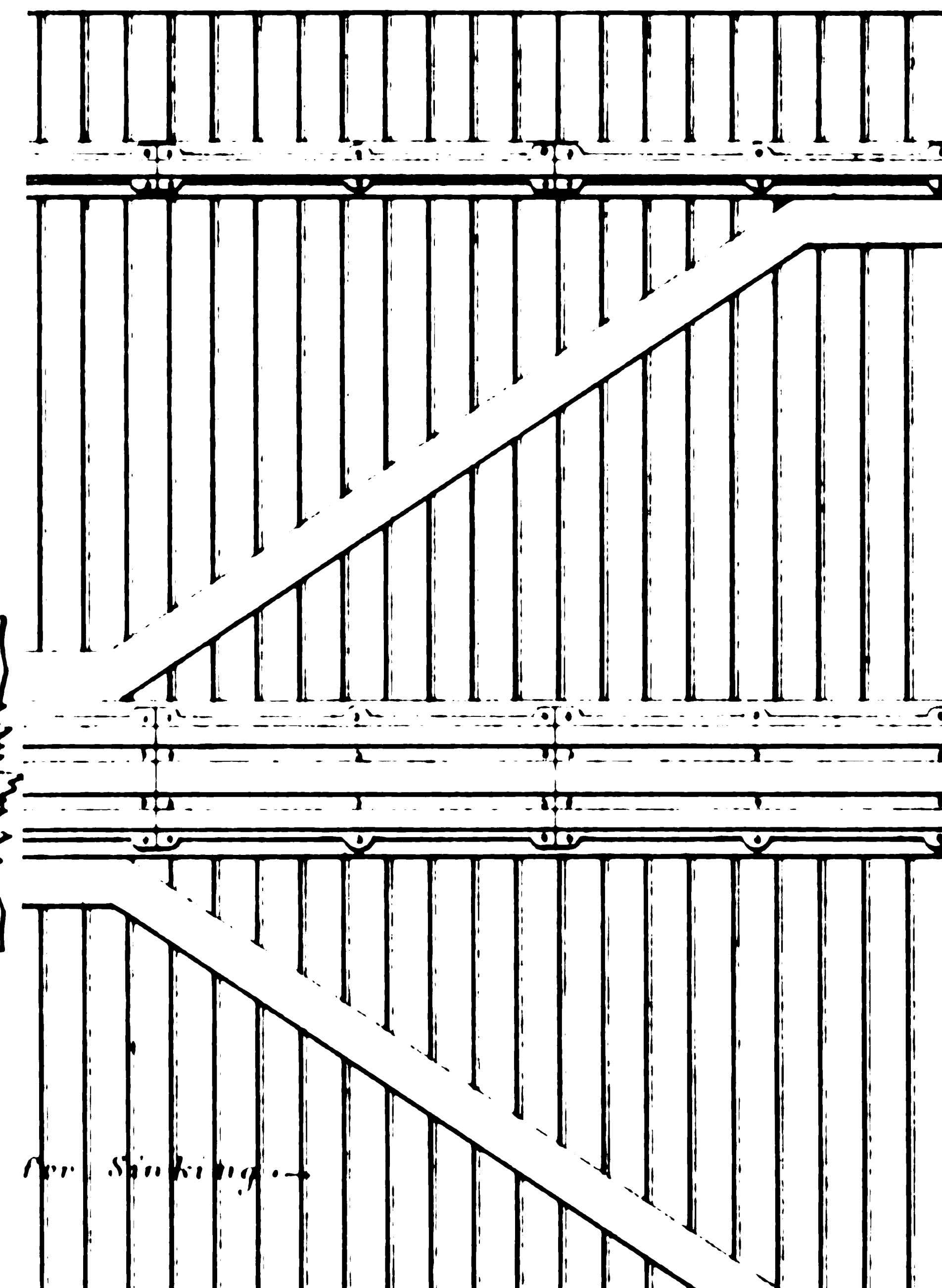

Minutes of Proceedings of the Institution of Civil Engineers

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. LXXII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. lxx., p. 444, line 5 (and errata of vol. lxxi. Lith.), for "Eith," read "Eyth."
„ lxxi., p. 77, lines 4 and 5 from bottom, for "E," read "E_1."
„ „ p. 172, line 13 from bottom, for "314," read "378."
„ „ p. 173, line 11, for "boiler," read "boilers."
„ „ p. 407, line 4, for "February," read "May."
„ lxxii., p. 2, line 4, for "Beek," read "Belk."

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has been made of late years in the Proceedings

The following Candidates have been balloted for and duly elected as

Members.

WILLIAM BEEK.
JOHN CHAMBERS.
WILLIAM HENRY LE MESURIER.

Associate Members.

THOMAS ADAMS, Stud. Inst. C.E.
WILLIAM BARRINGTON, Jun., Stud. Inst. C.E.
ROBERT HAROLD BROOKHOUSE, Stud. Inst. C.E.
JESSE CLARK.
HORACE BOARDMAN COX.
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WILLIAM SPINKS, Stud. Inst. C.E.
ALFRED SUMMERSCALE, Stud. Inst. C.E.
ROBERT WILSON.

Associates.

FUNG YEE.
GEORGE BROWN GODFREY.
JOHN WILSON THEOBALD.

Mr. BRUNLEES addressed the Meeting in the following terms on taking the Chair, for the first time, after his election as President:—

GENTLEMEN—

It is just thirty years since I had the honour of being elected a Member of this Institution. I felt justly proud of that position; but I did not then presume to imagine that I should ever attain the great distinction of occupying this chair. By electing me your President you have conferred on me the greatest honour in your gift. I thank you most sincerely for your kind suffrages, and I feel satisfied that you will favour me with the same ready and cordial support which you have always accorded to my predecessors.

I shall endeavour to preside over your interests and your deliberations with discretion and impartiality, and to do all in my power to augment the growth and utility of this increasingly prosperous Institution.

When I joined it in 1852 there were 745 members of all classes; the number now is 4,210. Then only one volume of "Minutes of Proceedings" was issued annually, now the number is four. There

was then no Benevolent Fund in connection with the Institution, nor had the Student class been established. The former was founded in 1864, and I may say with confidence that it has been a great boon to many who have been laid low by sickness or been overtaken by adverse circumstances; and it is a pleasing thought that, while you have been engaged in developing the material resources of our country, and in promoting works which increase the comfort and well-being of society, you have not forgotten the wants of those members who have been unfortunate in their profession.

The Student class was established in 1867, and has now 759 members. To this class of the Institution I look hopefully, because I believe that it affords valuable training for our future Engineers. The Student, who must be a pupil of a Corporate Member of the Institution and have had suitable preliminary education, has the opportunity of attending the Ordinary Meetings of the Institution in addition to those of his own section. He has at his command our valuable library, which contains not only the important technical literature of this country, but foreign works of note on Engineering science and practice. The advantages that may be obtained from these sources, combined with the practical experience acquired in the office and on the works of his master, afford the pupil, to my mind, the essentials of a complete training for the profession.

I would remind my younger hearers, however, that they are entering a field in which competition becomes yearly more keen; and that they cannot afford to despise the acquisition of knowledge, the immediate use of which, in their professional career, may perhaps not be self-evident to them. No knowledge that will make a man a better and a more acceptable member of society, none that enables him to hold his own as a man of the world, can be useless to the professional man. The knowledge acquired at school or at college requires not only to be kept up but expanded; the power should be cultivated of concisely and accurately placing your views and opinions before those who may be called upon to decide whether those views and opinions should be received and acted on, or laid aside and rejected, for it may have an important influence on your professional career, especially at the outset. At the Students' meetings you have the opportunity of exchanging ideas, and putting forth, both verbally and in writing, the opinions you may found on your studies, and I earnestly exhort you to avail yourselves of the opportunity to the fullest extent.

A change which has been made of late years in the Proceedings

of the Institution deserves mention. I allude to the scope of the Papers, which formerly were restricted chiefly to descriptions of executed works, but now embrace a wider range of subjects, affording much more matter for useful discussion, and of a variety which cannot fail to be interesting and valuable to all classes of Engineers.

My immediate predecessor in this chair, Sir William Armstrong, addressed you on the relations of Engineering science to the arts of war; and the soundness of his observations has since been strikingly exemplified by the rapid and decisive events of the recent campaign in Egypt. For some part of that rapidity we are indebted to the labours of the Civil Engineer, especially as regards the celerity and freshness with which our troops were enabled to take the field, and the ease with which material was moved forward by our ships and the railway, to say nothing of the service performed in the early stage of the land operations by the movements of the armoured train. For me, however, it is more fitting to follow the example of those Presidents who at different times have given some of the results of the conflict with Nature which engineers have to wage in the interests of peace and of civilisation.

I propose, therefore, in this Address to make a brief reference to some of the more important engineering works which have been recently finished, or are in process of execution. In considering these works we are forcibly reminded of the small progress that the arts of construction made until a period quite recent. We are obliged to confess that in nearly all that concerns work executed in stone, wood, or earth, the constructions of the ancient engineers may be put in comparison with some of the best modern works, and that in those materials it is not probable their works will ever be surpassed. I shall speak presently of the Panama Canal. When completed it will excite as much admiration, and be at least as important a link in water-communication, as the Suez Canal. But canals of great magnitude are amongst the earliest engineering works of which we have any record. History mentions at least two of importance; the canal for uniting the Red Sea with the Nile, and a canal across the Isthmus of Athos to avoid the navigation round the Peninsula of Chalcis, vestiges of which still remain. In regard to tunnelling, too, the ancients have not yet been so far outstripped as we might at first suppose. To carry off the superfluous waters of Lake Fucinus, the Emperor Claudius constructed a tunnel, which was 38 feet high, 28 feet wide, and 3 miles long, driven chiefly through solid rock. With the excep-

tion of explosives and machine drilling, it was apparently executed pretty much as work of that kind is executed in our day; but those exceptions show that it must have been executed with vastly more labour and time. A historian[1] who lived three centuries before our era tells many curious and wonderful things about the building of Babylon; but none more curious or wonderful than his description of the manner in which a passage was constructed beneath the River Euphrates from one bank to the other, a distance of more than 130 yards, so as to afford a passage for the inhabitants of the palaces on each side. The course of the river was diverted, a work of considerable magnitude, and a tunnel was constructed of brick, cemented inside and out with asphaltum. The walls, which were twenty bricks thick, were 12 feet high to the springing of the arch, and the width of the tunnel was 15 feet. The whole work is said to have been finished in two hundred and sixty days. There are remains of this subaqueous tunnel existing now, though it was constructed nearly four thousand years ago.

We have recently become as well acquainted with the City of Alexandria as we were with the Eddystone Lighthouse. It was on the Island of Pharos, opposite that city, that the first lighthouse was erected by Ptolemy nearly three centuries before the Christian Era. The name of the island became the name for a lighthouse in most European countries, and it is probable that down to a comparatively recent time the same principles of construction were followed, and the same materials were used. Winstanley's lighthouse at Eddystone, the first predecessor of the works of Smeaton and of Douglass, of which I shall have to speak, was probably not more efficient than the Roman pharos on the heights of Dover, some remains of which still exist.

Even the problems regarding the disposal of sewage, which puzzle municipalities, were attempted to be solved by ancient Rome, and dealt with by her engineers much in the same way that they have been dealt with in our day. A great "low-level" sewer, 30 feet high by 15 feet wide, received the drainage of a network of sewers coming from the city on the hills, and delivered the accumulation into the Tiber. It was the main artery of a system of sewerage and drainage which there had been no attempt to rival until, in quite recent times, the London sewerage system was carried out, and other large cities in this country and abroad have followed the example.

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[1] Diodorus of Sicily, Book II. c. i.

With the aid of manual labour and of the simpler mechanical contrivances, the ancient engineer did nearly all that was possible in earth, stone, and wood. It is the application of the power of steam, and the adaptation of machinery for the working of iron, which have of late years enlarged the field of the engineer, and led to the creation of works of previously unthought-of magnitude, with an ease, and with an economy of time, labour, and money never before approached. For, though iron is the most abundant and most diffused of metals, it only entered into works of construction in a secondary manner until the introduction of the steam-engine gave the force, and the machinist the appliances, for forming the metal into large masses.

We have recently, indeed, been entering on a new period of construction in iron; for, just when the application of that metal seemed to have reached its limit, the engineer has been enabled to take a new flight, by the aid of the genius of those who have turned our iron into steel, and given us the means of dealing with steel in masses as readily as with masses of iron. The result is, that some of the more formidable barriers to communication are being surmounted by the introduction of steel, and the engineer is called upon to design works which a few years ago would have been impossible of execution.

I will not trouble you with any further details of the use of iron in place of other materials, or of steel in the place of iron. I have said enough to illustrate the steady increase which is taking place in the means at the disposal of our profession for dealing with problems which were insoluble to previous generations of engineers.

I think you will agree with me that at no time since the foundation of our Institution have undertakings of greater magnitude, or greater social advantage, been entrusted to the members of our profession to design and execute.

The Forth Bridge, which is to be erected across the Forth at Queensferry, will be the largest bridge yet constructed. The design was referred by the North Eastern, the Midland, and the Great Northern Railway Companies, to their respective Engineers, our Past-Presidents, Mr. T. E. Harrison, Mr. W. H. Barlow, and Mr. John Fowler, and those gentlemen recommended the directors of the companies to adopt it, and it is now being carried out by Mr. Fowler and Mr. Benjamin Baker. The bridge will consist of two spans of 1,700 feet, two of 675 feet, fourteen of 168 feet, and six of 50 feet, with a clear headway for navigation of 150 feet above high water of spring tides. The two

largest spans are composed of two cantilevers, each 675 feet long, with a central girder 350 feet long, the depth of the cantilevers being 350 feet at the piers and 50 feet in the centre. To hold aloft and maintain the immense weight of steel of which the cantilevers and girder are composed, piers will be required of corresponding magnitude. The central pier, on the island of Inchgarvie, will consist of four cylindrical masses of concrete and masonry, 45 feet diameter at the top and 70 feet at the bottom. They will be founded on the rock at a depth below high water varying from 24 to 70 feet, and will be carried up to 18 feet above high water. The Queensferry pier will be similarly constructed, but its foundation will be the boulder-clay at a depth of from 68 to 88 feet below high water. The Fife pier will be founded on the rock at a comparatively small depth. Beyond their enormous size it is not expected that the construction of these piers will present any unusual features. The length of the bridge will be 5,330 feet, or more than a mile, and of the viaduct approaches 2,754 feet. The contract has been let for £1,600,000. The design of this bridge is a magnificent and bold one. Mr. Baker, in his description of it, says, "It compares with other railway bridges as a grenadier guardsman to a new-born infant. Bridges a few feet larger in span than the Britannia Bridge have been built elsewhere, but they are baby bridges after all." The ingenuity and forethought which have been employed in working out the details of the design appear to me worthy of it, and I am sure you will join with me in the wish that this enterprise may be carried through to completion without any mischance, and that its authors may reap the honour to which success will so justly entitle them.

A less remarkable work, but one of not less importance in its effects on the facility of communication between the railway systems of north and south, is the Tay Bridge, which is being carried out by Mr. W. H. Barlow. This bridge is to be erected on new and independent foundations on the up-stream side, and as near as conveniently practicable to the site of the previous bridge. It will be 10,780 feet long, divided into eighty-five spans, of which eighty-one will be crossed with iron girders, and the remaining four will be brickwork and masonry. The thirteen spans over the navigable water-way will be two of 227 feet, and eleven of 245 feet each, and the height from high water to the bottom of the girders will be 77 feet. The piers will be of wrought iron, plated all over, and supported on iron cylinders of suitable dimensions, sunk 20 feet into the bed of the river, and

filled with concrete and brickwork. The parliamentary estimate for the work was £654,000, but the contract has been let below that estimate. The bridge, which is for a double line of rails, is to be completed in three years.

Another bridge of a similar character is that over the River Ganges at Benares, which is being constructed from the design and under the superintendence of Mr. Batho, Mr. Barlow being the Consulting Engineer. It consists of seven large spans, each 356 feet from centre to centre of piers, and nine smaller spans 114 feet each from centre to centre of piers. Four of the large spans only are required to cross the river at its ordinary level, but during floods the river will pass through the whole of the sixteen spans. The depth of the river when at the ordinary level is about 20 to 30 feet, but the floods have been known to rise to a height of 50 feet above that, thus making the whole depth of water from 70 to 80 feet. The scour in the river bed is very great; therefore the foundations have to be sunk 120 feet into the bed of the river, which is entirely of sand. The girders are of steel, 25 feet apart, with a footpath of 5 feet in width on each side. The allowance for wind-pressure is 60 lbs. per square foot. The time of completion is estimated to be four years from the time of commencement. The bridge will be used as an ordinary road bridge, except at train times, when the road traffic will be stopped. The total approximate cost is £460,000.

A work of a different type from those already described is the Kinzua Viaduct. It spans a long narrow valley with lofty precipitous sides, on the Bradford branch of the New York, Lake Erie, and Western Railway. The viaduct is chiefly remarkable for its great height, which is 302 feet from the bed of the stream to the rails. Its length between the abutments is 2,051 feet, divided into twenty spans of 61 feet each, and one span of 62 feet. The girders are carried by wrought-iron towers or piers having a uniform width at the top of 10 feet and a span of 38½ feet. The upper half of the piers is composed of four and the lower of six wrought-iron columns, 1 foot in diameter, braced together and having a batter laterally of 2 inches per foot, so that the highest piers have a base of about 100 feet. As an additional stay against the force of the wind, the iron shoes at the bottom of the columns are bolted through the piers, and the columns themselves are braced together throughout their length. The work, which has a very light appearance, was commenced in August 1881, and was finished in October last, at a cost of £60,000. It is of course for only one line of rails.

Another type of bridge, which is now approaching completion, is the East River Bridge, between New York and Brooklyn. It is the largest yet made on the suspension principle. The total length is 5,989 feet, which is divided into three spans, the land spans being 930 feet each, the river span being 1,595 feet 6 inches, and its clear height above high water 135 feet. The width of the bridge is 85 feet, and it is intended to accommodate foot-passengers, railway trains, and ordinary street-traffic. The cables are four in number, each having a diameter of 15¾ inches. These cables are calculated to stand a strain of 12,200 tons each. There are two suspension-towers each 278 feet in height above high water, and 159 feet above the roadway. It is expected that this bridge, the finest bridge of its kind yet constructed, and one of the largest bridges in the world, may be opened for traffic in a few months. Its cost will be in round figures about £2,800,000, independent of the cost of land. Colonel A. W. Roebling is the Engineer in chief, Mr. F. Collingwood and Mr. C. E. Martin, Engineers in charge of the approach works, which, owing to the height of the main structure, are of unusual magnitude and importance.

From the consideration of bridges I now pass to the subject of tunnels. The longest tunnel yet constructed is the St. Gothard, having a length of 14,912 metres, or 2,692 metres longer than the Mont Cenis tunnel. It was begun at the northern end in September, and at the southern end in October 1872, and the whole work was completed and opened for traffic on the first day of 1882, or in a period of rather more than nine years. The different strata through which the tunnel passed, granitic and micaceous gneiss, micaceous schist, and other rocks, were not of extraordinary difficulty to penetrate with the compressed-air drills, though at the northern end of the work the gneiss was extremely hard. More difficult to effect was the passage of strata under the plain of Andermatt, which swelled on exposure to the air and water, and produced an enormous pressure. The first lining of 1 metre thick was forced in, and a second of greater strength was tried, but shared the same fate. This was entirely replaced by a lining of carefully cut stone 2½ metres thick at the foot of the arch, and gradually decreasing to 1½ metre at the crown. This lining has hitherto shown no sign of yielding, and it will probably prove efficient. The execution of this portion of the work was not only slow in itself but it greatly retarded the execution of the work beyond, as its reconstruction embarrassed the regular progress of the removal of spoil.

The northern end of the tunnel is 3,638 feet, and the southern end 3,756 feet, above sea-level. To overcome the sudden rise from the level of the railway proper to the mouths of the tunnel the engineers have constructed spiral tunnels of approach, which run above one another on a radius of 15 chains, and a gradient of one in 43·5. There are three of these spiral tunnels at the north, and four at the south, end of the great tunnel.

The Severn Tunnel, which is being carried out under the direction of our Past-President, Sir John Hawkshaw, is the largest work of the kind that has yet been undertaken in this country. It passes under the estuary of the Severn, about half a mile below the ferry which connects the Great Western Railway with the railways of South Wales. The total length of the tunnel is 7,942 yards, of which 3,960 yards, or 2¼ miles, are under the tideway. The greatest depth of water over the tunnel, at high water, is 96 feet, and at low water 60 feet. The tunnel passes through beds of shale and Pennant sandstone of the coal measures, and through the nearly horizontal beds of Keuper marls, which overlie these measures. Water has been met with in all the strata, sometimes in large quantities. One spring in the millstone grit, on the land approach to the tunnel, discharged over 5,000 gallons a minute, and its sudden inroad caused a temporary stoppage of the works. There are ten shafts throughout the work, and the quantity of water pumped from all of them is now between 7,000 and 8,000 gallons per minute. Under the deepest part of the estuary there will be a cover of 45 feet of Pennant sandstone. Under the Salmon Pool there is only a cover of 30 feet of red marl (Keuper). For excavating the rock, compressed-air drills are largely used. The tunnel is for two lines of railway, and is 20½ feet from the rail level to the soffit of the arch. It is 26 feet wide at 7 feet above rail-level. It is lined throughout with vitrified bricks set in Portland cement, the lining being from 1 foot 10½ inches to 3 feet thick. Over 1,400 lineal yards of tunnel and 910 lineal yards of arch from springing have been finished, mostly under the tideway. The total cost of the tunnel will be about £1,500,000, and it is hoped it will be completed in about four years.

The work of tunnelling beneath the River Hudson, between New York and Jersey City, is remarkable chiefly on account of the difficult nature of the material to be passed through, and the means employed for carrying out the work. There are two single-line tunnels, 30 feet apart, and parallel to each other, and they are intended to bring the railway traffic of the south-west and south

into the city of New York, from which that traffic is at present cut off by the Hudson. The width of the river at the point being tunnelled is 1 mile; its greatest depth at mean low water is 62 feet. The bed of the river consists of silt, coarse sand, and gravel. The tunnels are being driven by the pneumatic process. Greater difficulty is found in excavating the tunnels on the New York side by the same process, because the soil contains less silt and is looser, and offers comparatively little resistance to the pressure of the air. It is even a question whether, for the execution of this half of the work, the pneumatic system may not have to be abandoned, and recourse had to movable caissons, by means of which it is suggested that section after section of the tunnel could be built and connected.

The Mersey Railway, which I am carrying out, in conjunction with Mr. Douglas Fox, is intended to effect direct communication between the Lancashire and Cheshire railway-systems, and includes a tunnel 3,820 yards in length, between Liverpool and Birkenhead, 1,300 yards of which are under the River Mersey. The tunnel and drainage-headings below it are being driven through the Red Sandstone formation. These headings commence from shafts 1 mile apart, sunk on each side to a depth of 180 feet; they are carried on an ascending gradient to the centre of the river, where they will meet the main tunnel, which is constructed on a descending gradient to the same point. The heading from the Liverpool shaft has advanced 230 yards, and that from the Birkenhead shaft 400 yards.

Powerful pumping-machinery has been erected at each side, and at Liverpool, where the greatest quantity of water is met with, as much as 4,500 gallons per minute have been raised. At Birkenhead the water has never exceeded 3,000 gallons per minute. The main tunnel, which is for a double line of rails, is being driven from two independent shafts, and is carried forward from these landwards and riverwards simultaneously, and a length of 900 yards has been excavated. It is being lined with brickwork set in cement. The length of the Railway is 3 miles, and its cost will be about £1,000,000.

Before passing to another branch of this address, I would just mention one of the more important projects of the age, the Channel Tunnel. Upon the basis of researches made under the direction of Sir John Hawkshaw as to the nature of the strata on both sides of the channel and of the underlying sea-bed, an Act of Parliament was passed in 1875, at the instance of a company, of which Sir John Hawkshaw and I are the engineers, and a concession was granted

by the French Legislature to a French company, authorising certain preliminary works for this undertaking. Further researches were made by the French company in 1875–6, which resulted in their fixing a site for the French end of the proposed tunnel, about seven miles west of Calais. In England, as you are aware, the whole question has to come before Parliament shortly, and I therefore think it desirable not to do more than make this brief reference to the important project.

The proposal to unite the Atlantic and Pacific Oceans by a canal to be cut across the narrow neck of land which joins the two American continents is a very old one. During the last century-and-a-half many surveys have been made in different parts of the isthmus to demonstrate the practicability of the project. For some years it has been conceded to be physically practicable. It did not seem to be financially so until the very satisfactory pecuniary results of the Suez canal proved that merchants and shipowners were very willing to pay handsomely for the use of a route which would materially shorten voyages between important ports. Several schemes, resulting from independent and more or less accurate local investigations, were before the public, when Sir Ferdinand de Lesseps and his friends succeeded in obtaining a meeting of an International Congress in Paris in May, 1879, to choose the project which might be carried out by a public company. This congress adopted the general features of the scheme which is now being carried out.

It is proposed to be a canal without locks from deep water of the Atlantic to deep water of the Pacific, 73,200 metres long, 8½ metres deep, and having a minimum width at the water-line of 22 metres. The canal commences on the Atlantic coast, at the Bay of Limon, by natural depths of 8·50 metres, and goes through the marshes of Mindi, in the direction of the River Chagres, which it joins in the vicinity of Gatun. It is then kept up near to the river, which it cuts several times, and by a series of curves and straight lines reaches Matachin, where it separates from the River Chagres, and continues in a south-east direction along the valley of the Obispo, a tributary of the Chagres. It then enters the valley at the Rio Grande, and in a series of straight lines and curves reaches the Gulf of Panama near the islands of Naos and Flameneo, with a depth of 7·30 metres below the lowest tides. It is provided with passing places at suitable distances. The estimated cost of the canal is £31,200,000, including financial charges and management during construction.

One very important factor in the cost of the work is the nature

of the climate. That has always been described in the worst possible terms. So far experience has not borne out that description. The exact official figures of the mortality are given from February 1881 to April 1882. The result shows that so far from the mortality being excessive it does not exceed that of similar works executed in Europe. We can only hope that the canal may be completed and worked successfully, for the opening of such a passage between the two oceans cannot but be of vast benefit to the commerce of the world. It will abridge the voyage between Europe and the western coast of America at the equator some 2,500 marine leagues, and it will considerably shorten the voyage to the eastern parts of Australia, to New Zealand, and to China and Japan. The saving of time and cost of these long voyages must materially increase the commerce with those distant places, and lead to the interchange of commodities now prohibited by the cost of transport.[1]

Among works of interest for the shelter and accommodation of shipping I have chosen for brief reference the Alexandra Dock at Hull, now under construction by Mr. Abernethy, and the new Harbour of Port Elizabeth, which is being constructed from the designs of Sir John Coode.

The Alexandra Dock Works at Hull are situated on the left foreshore of the River Humber, some distance below the town, in great part seaward of the high-water line. The sea-embankments, upwards of 6,000 feet in length, have been completed, together with the cofferdam for the entrance-lock, and the tidal water excluded from the site of the dock and quays, together 152½ acres area. About 3,000 men, 20 locomotive engines, and 80 steam and hydraulic engines of various kinds, are employed day and night, aided by the electric light, in prosecuting the works.

For the first time in carrying out works of this class, the excavations and masonry are executed, in great part, by hydraulic machinery, worked by the permanent engines of 300 HP., having an accumulator with a plunger of 20 inches diameter and 35 feet stroke. The water space of the dock will be 2,300 feet in length and 1,000 feet in width, equal to an area of 46½ acres, walled all round, with jetties projecting into the dock at various points; the total length of wharfage or berthage afforded by the walls and jetties together being 9450 lineal feet.

The entrance-lock is approached by a trumpet-mouthed entrance

[1] Further details of this important work were given by Mr. Abernethy in his Presidential Address, 1881.

365 feet in extreme width, tapering gradually inwards from the tideway to the lock, which will be 550 feet in length between the outer and inner gates, and 85 feet in width, divided by intermediate gates into two lengths of 325 and 225 feet; the depth of water over the sill being 34 feet at springs, and 27 feet 10 inches at neaps.

Two graving-docks, entering from the main dock, are nearly completed, one 550 feet in length with an entrance 65 feet wide, and a depth over the cill of 21 feet 6 inches; the other 500 feet in length, with an entrance 60 feet wide, and a depth of 19 feet over its sill. The quays around the dock will average 320 feet in width.

Arrangements have been made for the shipment of coal, in addition to general traffic, on the most approved system; and railway communication will be formed between all parts of the quays. The works were commenced in March 1881, and will, it is stated, be nearly completed by the end of this year.

The harbour, as designed by Sir John Coode, for Port Elizabeth in Algoa Bay, on the eastern coast of South Africa, is of a different type. It solves the difficult problem of affording shelter for shipping from the heavy seas, so constantly rolling in upon the beach in that region, without obstructing the natural movement of the sand, which would speedily render any ordinary protection useless. Numerous very careful observations personally made by Sir John Coode, and information furnished to him by experienced persons on the spot, satisfied him that there was a prevalent "drift" or movement of the sand along the shores of the bay in a northerly direction, but that this movement was confined to the comparatively shallow water near the shore, and that it was caused by the heavy south-easterly seas to which this part of the African coast is exposed. As a first step towards the execution of the general design, a retaining-bank has been constructed along the shore at the southern end of the town, which has had the desired effect of clearing away a large quantity of the sand accumulations. From the northern end of this bank, a viaduct is to run out in a north-easterly direction seaward 3,000 feet, into 6 fathoms of water at low tide. This viaduct is to be formed of wrought-iron piles, placed in bays 30 feet apart, securely braced together, and supporting a deck of wrought-iron girders, with a plated floor carrying the road-surface on which rails will be laid in the usual manner and connected with the system of existing railways. This viaduct will present no obstruction to the sand-travel, and therefore cause no diminution of the depth of water, or in other words no extension of the shore seaward.

At the outer end of this viaduct the breakwater—the first section of which will be 2,000 feet long—is to be constructed of large concrete blocks, founded on a substratum of rubble, carried down to a sufficient depth to prevent disturbance by wave-action. This first section of the work, with its accessories, would give a total quayage of 2,160 feet, and to that extent provide complete shelter to shipping from the heavy rollers, which, under present conditions, occasionally prevent communication between the shipping and the shore for several days at a time. Provision is made for water, gas, and telegraph, and the whole cost of the work will be about £950,000.

The works for obtaining an improved supply of water for Liverpool are making rapid progress, under the engineers, Mr. Hawksley, of London, and Mr. Deacon, of Liverpool. The water is to be impounded from the watershed of the river Vyrnwy in North Wales, a distance of 67½ miles from the Prescot reservoirs, to which it is to be brought partly by aqueduct and partly in tunnels and pipes. The area of the watershed is about 22,000 acres. The upper waters of the Vyrnwy are to be impounded in the valley of the river by a dam 1,255 feet long and 84 feet high, which will collect the waters of the river into a reservoir having an area of 1,115 acres. The dam is formed of rubble masonry set in Portland cement, and is founded on the Caradoc beds in the lower Silurian formation. All the different works are in the hands of contractors, and are being actively pushed forward. Manchester recently obtained powers for an additional supply of water from Thirlmere. All are agreed that a supply of pure water is one of the most important means of maintaining the health of large towns, and it has also come to be admitted that it has an important influence on their moral condition. It would be well, therefore, if London would seek to emulate the enterprize and liberality of the northern cities in supplying its population with pure water.

I shall conclude the brief reference I have been able to make to the more remarkable engineering works of the day, with a few facts concerning the Eddystone lighthouse, a work so closely associated with the name of the Father of our profession—John Smeaton.

The old lighthouse, completed in 1759, has always been an object of peculiar interest to the nation, partly because it was the model on which all similar structures have since been built, and partly because of the sincere and simple character of Smeaton, his intense application to the work, and his great skill and power

of contrivance, which made a deep impression on all who were connected with him. It was with a feeling akin to personal regret that the public learned for the first time in 1877, from a Paper read by Sir James (then Mr.) Douglass before the British Association at Plymouth, that Smeaton's work was doomed, after an existence of little more than double the length of that of its immediate predecessor. It was a source of satisfaction and consolation that nothing in the design or construction of the tower itself conduced to the necessity for replacing it. The innumerable storms which had beset it during its existence of a hundred and twenty years had produced no effect on it; but the rock upon which it was reared had not been so enduring.

While I am sure that every one present shares the regret that has been felt at the fate of the old tower, they will rejoice at the completion of the new one by a member of our council, Sir James N. Douglass, who worthily earned the honour of knighthood by the achievement. The new tower is 130 feet high above high water, or 58 feet higher than the old tower. Four thousand six hundred and eighty-eight tons of stone have been used in its construction, or nearly five times the quantity (988 tons) used in the old building. Smeaton's tower contained only four rooms; that of Sir James Douglass contains nine, of larger and loftier proportions. There is, besides, a water-tank in the base, which did not exist in the old structure. It has cost £78,000, and it has been completed in the short space of three and a half years. I do not give any details of this important work, as doubtless a paper on it will be read in the coming session. Mr. E. Price Edwards has written an interesting account of it, to which he has very judiciously appended an abridgment of Smeaton's narrative of the building of the old tower. I will only add to this description these words of Mr. Edwards: "Let us hope that from this tower a light may shine for another hundred years at least, so that the perfected arrangements now completed may give matter to the criticism and wonder of our descendants. And let us hope that they, while admiring the beneficent spirit which prompted and directed the carrying out of so noble an undertaking, and marvelling at the completeness with which the work has been designed and executed, will help to realise something of Smeaton's hope of a 'possible perpetuity' for his tower, by recognising that the splendid structure set up in 1882 was but the outgrowth of his earlier labours completed in 1759."

While noting the erection of this important and interesting work, it may be well to refer to the progress that has been made

during the last quarter of a century in the lighting of lighthouses. Since the first practical application of electric light at the South Foreland Lighthouse on the 8th of December, 1858, considerable progress has been made with all the luminaries applied to lighthouses, viz., oil, gas, and electric lights. At the above date, the standard intensity of the first order oil light was 230 candle-units, and the intensity of the most powerful electric light was about 670 candle-units. Recently at the Eddystone Lighthouse two oil lamps, each of 720 candle-units, have been applied, thus giving an aggregate focal intensity of 1,440 candle-units. This is the highest intensity yet attained with oil light, but it will shortly be considerably exceeded. With electric light, a focal intensity of about 10,000 candle-units is applied at the Lizard, and arrangements are now being made by the Trinity House for practically testing the merits of an electric light of 60,000 candle units intensity. With coal-gas light great progress has been made since 1865 by Mr. John Wigham, of Dublin. In the latest development of his system four burners are employed, each of 1,250 candle-units intensity, or an aggregate intensity of 5,000 candle units.

I propose now to say a few words on the subject of foreign and colonial railways. The railway systems of Europe are still far from complete, especially in the east, where much remains to be done. Except in the extreme north and south of Africa, the locomotive has not yet penetrated, and almost the whole of that vast and productive country inland remains to be opened up. Brazil has made some important lines, but they bear no proportion to the extent of a country the natural resources of which are so various and so great. China is another country with which we have had for many years a very extensive commerce, and which might be greatly increased if there were improved means of communication between the interior and the coast.

We know that the Empire of China is of vast extent, and that it is densely peopled over a large part of its surface, and that though it has very bad roads, it has much excellent canal and river navigation. We believe that the immense population of China would derive great advantages from the construction of railways, and that, if carefully planned and deliberately carried out, the capital spent on them would produce an adequate return. There is no doubt that, if the Chinese Government were disposed to permit the construction of railways in China, either as government works or private enterprises, ample funds for their construction could be immediately found in Europe. It has been

said that the objection of the Chinese to the introduction of railways into their country proceeds chiefly from the fear of introducing foreigners in any considerable number. Mr. Morrison, the Engineer of the Woosung Railway, which you remember was bought by the government for the purpose of being destroyed has given me some information quite recently on the subject of railways in China, and I desire to lay before you the more salient points of it. It would appear that Chinese statesmen, even those most liberal and enlightened, really believed, up to a recent period, that railways were not adapted to the circumstances of China. They have recently formed a different opinion. An official memorial has been drawn up by one important government officer, and favourably reported on to the government by another high official, suggesting and recommending the construction of four important trunk lines, and no doubt if these were once executed many more would follow.

I will not now trouble you with the details of construction and cost, with which I have been furnished by Mr. Morrison, but speaking generally, and assuming that some 5,000 miles of main lines could be undertaken, single lines of the ordinary 4-foot 8½-inch gauge could be constructed and equipped for about £12,000 per mile. He considers that it is a fallacy to suppose that cheap, light, narrow-gauge lines would be serviceable for the main lines of the country, which is densely populated, and which can only be adequately supplied with railway accommodation by the construction of first-class roads of the ordinary gauge.

I infer from the report of the Government Director of Indian Railway Companies, that there are in course of construction in India somewhat more than 900 miles of railway, including in their course three bridges of more than ordinary importance; that across the Indus at Attock having two spans of 300 feet each, and three of 250 feet; that over the Ganges at Benares, particulars of which I have already given; and that over the Hooghly, about 20 miles above Calcutta. The last was designed by Mr. Rendel and Mr. Bradford Leslie. Other lines are contemplated, and to some extent determined on. When those now in progress are completed, India will have nearly 12,000 miles of railway open for traffic.

In New Zealand the length of railway in various stages of progress during the year ending the 31st of March last was 234 miles, and 1,333 miles were then open for traffic, and an additional expenditure of £1,650,000 had been ordered.

In Queensland only a few miles appear to be under construction.

But an extensive system of railways is at present under the consideration of the Government.

In South Australia considerable progress has recently been made in railway building, and still further extensions are contemplated; and this may also be said of Victoria and New South Wales, where there are 442 miles under construction. It seems to me, looking on from a distance, and taking a broad view of the Australian continent—the populations of which must gradually approach each other, though now widely separated—a thing greatly to be regretted that these Colonies have not adopted the same gauge for their lines. With the disadvantages which have arisen in England, in India, and in America, from a break of gauge, and from the great advantages which western and central Europe have derived from a uniform gauge, it might have been thought prudent on the part of the Australian colonies to accept the experience of older communities. But in Queensland they have adopted the 3-feet 6-inches gauge; in New South Wales the 4 feet 8½ inches; in Victoria 5 feet 3 inches; in Western Australia 3 feet 6 inches; and in South Australia 5 feet 3 inches and 3 feet 6 inches, and they propose to use the metre gauge also.

In Canada, according to the last report of the Railway Department, there were 2,910 miles of railway under construction; and in the United States it has been stated, unofficially, that there were some 11,000 miles constructed during last year. Both these mileages are in excess of previous years. In the United States and in Canada the tendency is towards a uniformity of gauge; and when it is considered what great advantages there are in uniformity, not only as regards the interchange of traffic, but of rolling stock, we may look for its being complete in America before long.

The undue neglect of the inland navigation of this country has recently been brought under public notice, and it is a subject which eminently deserves the attention of the engineer. It is not my intention to discuss the relative advantages of railroad and water conveyance. For the conveyance of coarse goods, the bulk of which is out of proportion to their value, a slower conveyance than the goods-train might be endured in consideration of its greater cheapness. But to be more extensively useful it must be something between the present speed of the canal-boat and the goods-train, with the punctuality of the latter. It appears to me that our attention should be directed first to improving the construction of our canals and their lockage, and secondly to the means of increasing the rate of speed on them by better modes of

traction than those at present existing. If, by improving canals and canal-traction, you can treble or quadruple the rate of speed, the canal will be able to compete successfully with the railway, and may supersede it economically for the conveyance of many classes of goods and minerals, of which probably the railway would be advantageously relieved.

I have now laid before you, as succinctly as I have thought consistent with clearness of description, the principal and distinctive features of some of the more important works of engineering science which have been recently executed, or which are in course of construction, and I have mentioned some of the countries of great extent which still remain to be supplied with the works of the engineer. I have ventured to recall to your recollection some of the great engineering feats of ancient times achieved with the materials which nature has placed ready to the hand of man; I have reminded you of the comparatively little progress that was made in the constructive arts until a period quite recent; and I have drawn your attention to the enormous development of those arts by the use of iron, which was only begun on a comparatively large scale within the memory of men still living.

When we consider the magnificent engineering works of ancient times, the creation of ages we call barbarous, in countries which were, by comparison with the nations of our day, sparsely peopled; subject continually to war, pestilence, and famine, or the ruinous consequences of frequent organic political changes; without accumulated capital or the ready means of exchanging products, to say nothing of the absence of facilities for that rapid intercommunication of discovery and of thought which has had such marvellous and beneficial influence of late years on every department of art, science, and literature, we cannot but be astonished, not at the magnitude of our own works, but that all the immense advantages which we enjoy should have been enjoyed so recently, and should up to these latter times have been turned to so little profit.

In our own country the trained engineer is a comparatively modern creation. Until little more than a hundred years ago we had hardly a canal or a passable high road. Two centuries ago it was necessary to send to Holland for an engineer to build a sea-wall. I am happy to say we have been able to repay our Dutch friends by lending them an English engineer (Sir John Hawkshaw) to build for them one of the finest works of canalisation that has yet been executed in any country. We have only begun

to take in hand the embankment of rivers, and what the engineers of the first Napoleon did for Paris at the beginning of the century was only done some fifty years later for London by our colleague Sir Joseph Bazalgette, under the Metropolitan Board of Works.

We have still no authority competent to deal with the general system of our rivers. A Rivers-Conservancy and Flood-Prevention Act is greatly needed. Private interests of the most insignificant character are suffered to interfere with or prevent the execution of plans which would be of manifest advantage to large populations. To carry out any local or general public improvement, private persons must be organised into public bodies, and appeal must be made to the cumbrous and costly machinery of parliamentary legislation in every individual case. There are signs that this ancient system, suitable enough for the rate of progress of public works half a century ago, but unsuited to the rapid march of improvement in our time, will before long be modified and improved. More ready and less expensive machinery for authorising public works of utility will tend to increase them, and their increase will offer an enlarged field for the employment of engineering skill. In the reclamation and drainage of land and the sewerage of towns, and in their water supply, there is still a large amount of work to be done.

We have heard, during the recent times of depression, fears expressed that the profession was too full, that we had completed our work in the land, and that the future was not for us. But these fears are vain. So long as capital accumulates in this country, it must be expended in some productive way at home or abroad. Judiciously planned public works are always productive and the men who find the means will appoint the agents for carrying out their works, and those agents will always be their own countrymen, so long as they are competent to perform the duties demanded of them. We have been told that foreign competition was displacing even our iron manufactures in both the home and the colonial markets, and instances have been cited to prove the general fact. But for price and quality the British iron manufacture is still unrivalled. I see no reason to fear that it will easily be displaced from its present position. Be sure of this, that while we remain the greatest capitalists of the world, and the chief iron-producers of the world, the world at large will be glad to come to us for our capital, our material, and our scientific skill.

Alarming pictures are sometimes drawn of the fearful results of the conflicts between capital and labour in this country, and of their baleful influence on contracts for public works. We have not a

monopoly of these conflicts, and so far they affect other countries equally with our own. No doubt, sudden disturbance of the labour market is a serious evil; but it is a temporary one, and common sense or self-interest prevents the evil from becoming chronic. In the time of Charles the Second, Macaulay[1] tells us there was "a vehement and bitter cry of labour against capital." The weavers of Leeds and Norwich, employed in the woollen manufacture, seemed bent on destroying it by their demands. But the woollen manufacture is still one of the great staple industries of England. In a free country trade-disturbances right themselves. The law of supply and demand never fails, if left to its own operation, to restore the balance.

Gentlemen, the field of the engineer is the world. You see that the old natural barriers which stopped or impeded communication are being gradually surmounted. The bridge or the tunnel is taking the place of the ferry for the passage of rivers, of arms of the sea, and even of the sea itself. The ferry-system of New York, the most complete in existence, is giving place to a bridge in one place and a tunnel in another. In our own country the necessities of the traffic between South Wales and the South West of England have compelled the substitution of a tunnel under the Severn for a ferry. The enormous traffic between Liverpool and Birkenhead, served for many years by excellent steam-ferries, can, it is found, only be adequately accommodated by a railway tunnel beneath the Mersey. The engineer of the Metropolitan Board of Works, Sir Joseph Bazalgette, has recently presented to that Board a Report and Plans on the Communications between the North and South of London below Bridge. He has recommended the construction of a tunnel at Shadwell and a tunnel at Blackwall, and a high-level bridge at the Tower, at an aggregate cost of £5,200,000. Tunnels under the Thames have been proposed since the beginning of the century, and Mr. Trevithick nearly completed a heading from shore to shore in 1807. It is probable that the tunnels now recommended, and many more, would have been made earlier if the Thames Tunnel of Brunel had been planned on a less magnificent scale, or had been carried out under circumstances of less difficulty and cost. The small tunnel of Mr. Peter Barlow, from the Tower to Horselydown, wisely planned and successfully carried out with great ease, rapidity and economy, has been of much advantage to the working classes, and has served to show, in spite of former failures, that there is no

[1] Hist. Eng., chap. III.

difficulty in tunnelling beneath the river at a suitable depth. No one who considers the vast advantages of direct and uninterrupted access between the two parts of London lying north and south of the Thames below London Bridge, containing a commercial and manufacturing population equal in numbers to the combined populations of Liverpool, Manchester, Salford and Birmingham, could doubt the wisdom of some such recommendations as those made by Sir Joseph Bazalgette.

Not only are works such as these, as well as many new or larger harbours and docks required at home; not only are new countries of vast extent and enormous resources being gradually laid open to the operations of the engineer, but a greater diversity of employment is offered to him. We have hardly reached the limits within which steam, gas, and water can be usefully employed, when a new agent affords the engineer new sources of activity. It is impossible to say to what uses the comparatively new power of electricity may be put, but it is easy to see that it will play an important part in the social and industrial economy of the age.

At any rate it is clear to me that whether we look at home or abroad, to the development of old forces and the uses of old materials, or to the discovery of new forces and new materials, the occupation of the engineer must grow and increase. It is an essential object of this Institution to draw from all quarters of the globe, and to record for your information, the results of the investigation, the thought and the experience of our profession. We meet here for the interchange of ideas on all that concerns the execution of public works. We have laid before us from time to time descriptions, in minute detail, of the more important works executed by the most accomplished members of the profession. While we diligently seek information from the vast storehouse of experience and skill which is provided for us by the Institution, and carefully adapt our professional knowledge to the new conditions under which we may be called upon to work through the changes which time effects, we shall be able to take part successfully in the operations which it is the business of our profession to carry out, and which are at once the seed and the product and the evidence of civilisation.

It only remains for me now to acknowledge the readiness with which my brother engineers and others have supplied me with information, and to thank you for the attention with which you have listened to this Address.

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16 January, 1883.

JAMES BRUNLEES, F.R.S.E., President,

in the Chair.

A communication was brought forward from the Council announcing that arrangements had been completed for the delivery at the Institution, on Thursday evenings, of a course of six lectures on some of the Practical Applications of Electricity, as under:—

Feb. 15. "The Progress of Telegraphy." By Mr. W. H. Preece, F.R.S., M. Inst. C. E.
Mar. 1. "Telephones." By Sir Frederick Bramwell, F.R.S., V.-P. Inst. C. E.
Mar. 15. "The Electrical Transmission and Storage of Power." By Dr. C. William Siemens, F.R.S., M. Inst. C. E.
April 5. "Some Points in Electric Lighting." By Dr. J. Hopkinson, F.R.S., M. Inst. C. E.
April 19. "Electricity applied to Explosive Purposes." By Professor F. A. Abel, C.B., F.R.S., Hon. M. Inst. C. E.
May 3. "Electrical Units of Measurement." By Sir William Thomson, F.R.S., M. Inst. C. E.

(*Paper No. 1907.*)

"The Antwerp Waterworks."

By William Anderson, M. Inst. C.E.

In the year 1873 a concession for the supply of water to the city of Antwerp was granted to two gentlemen, who did not, however, carry it into effect. In 1879 this concession fell into the hands of the Author's firm, which carried out the necessary works and disposed of the undertaking in full working order to the Antwerp Waterworks Company.

The city of Antwerp has a population of 200,000 inhabitants; it ranks as the third largest port in Europe, and is being rapidly

extended in every direction. The Municipality has long been engaged in very important works connected with the extension of the quays and the construction of docks, under their engineer, Mr. G. Royers, while the removal of the old fortifications has given opportunities for the formation of extensive boulevards and streets, which are being rapidly occupied by handsome houses. The water-supply, before the establishment of the waterworks, was derived chiefly from wells sunk in the sandy soil, often in close proximity to cess-pits into which most of the drainage of the town was directed. Some of the water, however, and especially that used in breweries and other factories, was taken from open canals, and was in most cases very impure. The shipping and factories at a distance from the canals were principally supplied by water-carts and barges at great cost, the rate for water rising as high as 5 francs the cubic metre, or 19*s.* per 1,000 gallons.

The sewerage arrangements of the city were, and are still, very imperfect. Nothing but surface-water is allowed to discharge into such drains as exist, while most of the sewage is received by brick cess-pits, more or less watertight, emptied periodically by night-carts; but the soil being sandy and porous, this arrangement makes the use of wells for water-supply especially dangerous. The water, besides being impure, is hard and ill-adapted for use in steam-boilers, on account of the thick deposits which speedily accumulate on the heating surfaces.

Numerous schemes for the supply of the town with water had, from time to time, been brought forward by various engineers, but the only plan which seemed practicable, from a financial point of view, was the one proposed by Mr. Joseph Quick, M. Inst. C.E., namely, to take the water from the river Nethe, at a point 11 miles from Antwerp; yet the quality of that source was such that the commercial success of a water company would have been doubtful, had not means been at hand for converting the only available supply into the brilliant and wholesome water now being delivered to Antwerp.

For many years Mr. Gustav Bischof had been advocating the use of finely divided, or spongy metallic iron, as a medium for the filtration of water.[1] He had demonstrated—and his results had been confirmed by the independent labours of Frankland,[2]

[1] Proceedings of the Royal Society of London, 1878, p. 258: "On Putrescent Organic Matter in Potable Water." "Sanitary Notes on Potable Water," read before the Society of Medical Officers of Health, May 1879.

[2] Sixth Report of Rivers Pollution Commission (1868), p. 220.

Hatton,[1] and Mr. G. H. Ogston, Assoc. Inst. C.E.—that filtration through spongy iron destroyed much of the organic impurity, removed colour, precipitated very finely-suspended solid matter, reduced hardness, and, above all, destroyed with certainty the germs of putrefaction, and most probably those of all kinds of epidemic disease.

Mr. Bischof had already established a considerable business in domestic filters; and, by a fortunate chain of events, the works where the manufacture of the material was provisionally conducted were capable of producing largely beyond his requirements, and on a scale which would make the manufacture of 1,000 tons possible at a moderate cost and in reasonable time. Mainly from confidence in the powers of spongy iron, and the consequent certainty of a prosperous future for a water company, the Author's firm, after many months of weary negotiations and law proceedings, succeeded in disentangling the project from the difficulties surrounding it, and entered into cordial relations with the Municipality, which was most anxious to see the long-delayed works carried out.

The river Nethe flows in a south-westerly direction, and is crossed, at the village of Waelhem, by the road from Antwerp to Malines, at a point 11 miles from Antwerp. About 2 miles below Waelhem, at Rumpst, the Nethe joins the Dyle, on which Malines is situated, and another stream called the Senne, and with them forms the Rupel, which falls into the Scheldt about 10 miles above Antwerp. It was decided to place the pumping-station at Waelhem, where suitable land was obtainable, and where the high road afforded excellent means of access and facilities for laying the main. The whole of the rivers in the neighbourhood are tidal, the ebb occupying about seven hours twenty minutes. At Waelhem the tide ranges between + 3·61 feet[2] and + 17·06 feet, a variation of 13 feet 6 inches. In order, on the one hand, to avoid taking in the polluted waters of the Rupel carried past Waelhem on the flood tide, and, on the other, the waters of the Nethe, contaminated, at low-water, by the towns situated above the intake, the authorities decreed that the water should not be taken into the settling-ponds before three hours after high-water, and that the level of the bottom of the intake-culvert should not be lower than + 3·94 feet above

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[1] Journal of the Chemical Society, 1881, p. 258: "On the Oxidation of Organic Matter in Water by Filtration through various Media." Also 19th Army Medical Report, 1877; Case of Fort George.

[2] Datum is average low water at Ostend.

datum. Water taken under these conditions, and purified by ordinary sand filtration, was pronounced by the authorities to be sufficiently good for the supply of the city; but owing to its peaty origin, and the muddy nature of the banks between which it flowed, it was considerably coloured, was permeated by a very fine mud, which could not be removed, either by subsidence or by ordinary filtration, and had a disagreeable taste. Such water could not enter into successful competition with the existing domestic supply, which, though greatly polluted, was nevertheless bright and sparkling, and possessed of an agreeable flavour.

Laboratory experiments conducted by Mr. Ogston gave strong grounds for hoping that Mr. Bischof's method of filtration would remove what was objectionable in the appearance of the Nethe water, while in every important respect of purity, softness, and freedom from dangerous germs, it would be greatly superior to the supply with which the citizens had hitherto been obliged to be content.

But as laboratory experiments, though serving as valuable guides, cannot be implicitly trusted, it was determined to try the new process on a large scale at Waelhem, and to work it for several months. It was hoped that not only would Mr. Ogston's expectations be confirmed, but that positive data would be obtained as to the rate of filtration best adapted for the system. The following was the process decided on, after careful consideration, by Mr. Bischof, Mr. Ogston, and the Author. It was determined, in the first instance, to provide for twelve hours' subsidence of the river water, to allow the grosser particles of suspended matter to settle; next, the water was to be decanted from the surface on to a layer of ordinary filter-sand, underneath which would be a bed of spongy iron and gravel mixed; the water was then to be exposed as much as possible to the air, in order to oxidize any iron it might have dissolved, and finally it was to be passed through an ordinary sand-filter, in which the red iron oxide would be separated.

The process above described was carried out in the following manner, Plate 1, Fig. 1:—

A 9-inch pipe was laid through the river bank, at the height prescribed by the concession, and admitted the water into either of two settling-ponds excavated in the ground, and capable of containing 30,000 gallons apiece. Each pond was fitted with a floating suction-pipe which enabled the water to be decanted from the surface down to a depth of 18 inches from the bottom.

A duplex steam-pump delivered the water continuously and at

a fixed rate, ranging up to 36 gallons per minute, on to the filters, which were two in number, first the higher or spongy-iron filter, and secondly the lower or sand-filter. The spongy-iron filter consisted of a cast-iron tank, 18 feet 6 inches square, and 11 feet deep, raised 3 feet 10½ inches above the ground. Its bottom was coated smoothly with cement-concrete, and on this was laid a bed of bricks on edge, forming channels covered closely by bricks on flat. On the layer of bricks was laid a bed 3 feet thick of spongy iron, mixed with gravel in the proportion of 1 part by measure of iron to 3 parts of gravel, and over that a layer 1 foot 6 inches deep of fine-dredged river-sand from the Meuse. From the middle of the bottom of the tank a 3-inch pipe, with a regulating-cock, took the partially-filtered water to the second or lower filter, which was also a cast-iron tank 18 feet 6 inches square, but only 7 feet 6 inches deep, with the bottom raised 1 foot 6 inches above the ground, and cemented in the same way as that of the upper filter. It was filled first with a layer of 15 inches of small gravel, and over that a bed 2 feet deep of Meuse river-sand. The depth of water over the upper surface of the sand in both filters was to reach a maximum of 4 feet, the lower filter being placed at such a level that the surface of its sand was 4 feet below that of the upper filter. The filtered water was drawn off by a 3-inch pipe, terminating in a swivel length working in a vertical plane, and arranged so that its open end could be fixed at any desired level below that of the water in the filter, and a constant head be thus readily maintained.

The filters were set to work on the 23rd of November, 1879, and notwithstanding the exceptionally severe weather, Messrs. Bischof and Ogston were enabled to carry out experiments extending over a period of three months. They arrived at conclusions which were satisfactory both as to the degree of purification possible, and the rate at which the filters might be worked. The only point which could not be determined, in the time available for experiment, was the rate at which the iron would be used up; but laboratory investigations, and experience with domestic filters, seemed to indicate that the iron wasted very slowly. Upon the strength of the favourable reports thus received, the Author's firm decided that they were warranted in adopting Mr. Bischof's process, confident that no difficulties would arise but such as could be met without serious annual expense.

The country about Antwerp being very flat, no elevation exists within available distance for a service-reservoir, and as it was not thought desirable to burden the undertaking with the cost of a

water-tower of sufficient height to give the pressure prescribed by the concession, viz. 5 atmospheres or 170 feet, it was decided to pump continuously night and day by means of pairs of engines so coupled and balanced that they would run at any speed between one and a half revolution and twenty-two revolutions per minute. It was also determined to provide sufficient storage-room for filtered water at the pumping station, so as to allow the filters to act steadily while the engines worked at speeds varying according to the demand in the city. The works at Waelhem were to consist of two settling ponds, three spongy-iron filters, three sand-filters, two filtered-water reservoirs, two 12-HP. engines, and screw-pumps to lift the water out of the settling-ponds on to the filters, two sets of 170-HP. pumping engines, four boilers, air-vessels, and a 20-inch main to Antwerp.

The terms of the concession required a daily supply of 150 litres or 33 gallons per head for 175,000 inhabitants, but it was provided that in the first instance the works at the intake and the main to Antwerp should only be constructed for 40 per cent. of that amount, the municipal authorities reserving the right to demand the extension of the pumping-station so soon as they considered that the service of the town required it.

About 13 acres of land were purchased at Waelhem in the angle formed between the river and the Malines Road, Plate 1, Fig. 2. The ground is of a treacherous nature. The mean level is 10·17 feet above datum, or about half-tide level, the river being confined between banks the crests of which rise to 20·83 feet above datum. Trial holes showed a very unequal formation. First, a depth of 18 inches of alluvial deposit and clay; next, in some places, peat; in others stiff brick clay, and in others running sand. At a depth of 6 to 7 feet a layer at least 28 feet deep of silver-grey sand, full of water, extended over the whole area, and, in addition, there was a band of coarse brown sand unlike anything in the neighbourhood, and which was said to be the filling-in of military trenches dug for the defence of Antwerp during the war of 1830. It was determined to build the foundations of the engines, boilers and their houses, together with that of the chimney, on a platform of piles, but to let the rest of the work float on the surface of the land, using as little masonry as practicable, so that any possible subsidence might be uniform over the whole surface.

The conditions under which the water was to be admitted allowed only three-quarters of an hour in each tide for filling the settling ponds, Plate 1, Figs. 3 to 7. To meet these circumstances a 42-inch cast-iron pipe 150 feet long was laid through the river bank

with a slope of 1 in 36, the bottom of its mouth being 3·94 feet above datum. This pipe, on the land side, divides into two branches, each branch being fitted with a sluice, and discharges by means of a diverging adjutage into either of the two settling-ponds. The pipe is secured in the river bank in the manner indicated. The sluices are actuated by hydraulic cylinders worked by the pressure in the main.

The two settling-ponds were excavated in the natural ground, with slopes of $1\frac{1}{2}$ to 1, and contain, between the levels + 2·07 feet and + 8·07 feet, 1,320,000 gallons of water each. The bottoms are finished at + 1·07 foot, allowing 12 inches for the collection of sediment. The bottoms and sides of the ponds were paved with slabs of stone about 5 inches thick, laid dry for the most part, to prevent the land-water from forcing in the lining, but a few tiers all round the top were set in cement as a protection against displacement by ice, and the same course was pursued for 60 square yards about the mouths of the intake pipes as a guard against disturbance by scour. Though sunk 10 feet in the ground these ponds were almost free from land-water, and the comparatively narrow bank, only 9·84 feet wide on the crest dividing them, proved perfectly tight when one pond was empty and the other full, that is to say, under a head of nearly 7 feet.

For the removal of sediment a 12-inch centrifugal pump, actuated by a partial turbine worked by the pressure from the main, is placed in the valve-house and discharges into the river the mud which it takes from either settling pond, by means of a 12-inch branch pipe governed by a sluice-cock. This pump further serves to empty the filters when it is necessary to clean or examine them, and for this purpose is connected to their wash-out pipes by a 12-inch pipe laid diagonally across No. 1 settling-pond. It has also a 12-inch branch and cock leading to a sump to which all the land drains are connected, so that in the event of heavy and continuous rain the land-water can be pumped out.

Across the bottoms of the two ponds, at the ends furthest from the river, is laid a 24-inch main, one end of which is prepared for extension to future settling ponds and the other terminates in the screw-pump house, but so that it can be readily extended to a future pumping-station. In each pond is a 15-inch branch to which is connected a sluice-cock and swivel decanting-pipe, the upper end of which is floated by two galvanised-iron buoys, secured to either end of a T-pipe wherein is formed a weir protected by a grating. The flotation of the buoys can be regulated

by the admission of water, and, in hard frosts, they are sunk altogether, so as to avoid difficulty with the ice.

Adjoining the main pumping-engines is an annexe containing two Airy's screw-pumps, each driven by an independent 12-HP. horizontal non-condensing engine, Plate 2. The screws are 42 feet long and 3 feet in diameter, laid at an angle of 30°, arranged for a maximum lift of 19 feet, and capable of delivering up to 2,000 gallons per minute. Besides the extreme simplicity of these pumps, and their high efficiency, they have the advantage of being excellent water-meters, the delivery being very nearly the same per revolution at all speeds and all degrees of immersion of the pump on the suction side. Advantage is taken of this property for keeping a record of the amount of water raised daily into the filters, by noting the number of revolutions made by the screws. The pumps deliver into cast-iron hoppers connected to a 20-inch main, which carries the water to the spongy-iron filters. The hoppers are fitted with overflows to allow any excess to fall back into the pump-wells, and with screw valves to regulate the connection with the 20-inch main. The 24-inch supply-pipe from the settling-ponds to the pumps has a 12-inch branch governed by a sluice-cock to each of the pump-wells, so that either of the screws can be isolated and laid dry for examination or repair. The exhaust steam from the 12-HP. engines is carried to a spiral-coil feed-water heater, and is almost entirely condensed by warming the feed-water supplied to the boilers.

One serious difficulty had to be met, and that was the action of frost upon the filters. To provide for this it was decided to warm the water raised by the screw-pumps a few degrees, by the injection of live steam. Each pump-well is accordingly fitted with a 3-inch steam-pipe terminating in a common mushroom-valve opening outwards; this valve completely prevents the crackling and concussion which usually follow when steam is injected into cold water. When the pumping-machinery is worked at full power a rise of 1° Fahrenheit of temperature will require 15-horse boiler power. During the last mild winter the arrangement worked very well all through a week's continuous frost, and kept the filters clear of ice at a very moderate cost of fuel.

The spongy-iron filters, Plate 1, are entirely above ground, and are formed of embankments made from the soil excavated from the settling ponds. The crests of the banks are + 19·95 feet, and the bottoms of the filters + 10·17 feet, or on the natural level of the ground. The tops of the banks are 9·84 feet wide on the side next the settling-ponds, 19·69 feet wide on the further side,

and the same width between and at the outsides of the filters, this extra width being allowed for sand washing and for keeping a stock of filtering material. The level of the top of the sand is + 15·84 feet, and at this height each filter is 101·71 feet by 101·71 feet. The slopes, both inside and out, are 1½ to 1. The filters are filled in the following manner:—On the top is a depth of 2 feet of Meuse sand, then a layer 3 inches thick of fine gravel, and, finally, 3 feet of spongy iron and gravel mixed, as in the experimental filter, in the proportion of 1 part of iron by measure to 3 parts of gravel. The filtering material rests on a close layer of brick, on flat covering channels of brick on edge, all laid dry. The earthwork is puddled 18 inches thick all over the inner surfaces; this is protected by a layer of 6 inches of hydraulic lime concrete; and above the level of the filtering material it is further protected by paving sets about 5 inches thick, the puddle being reduced to 12 inches thick. The bottom falls 6 inches each way to a cross channel which has an additional fall to the centre, where it discharges into a 12-inch cast-iron pipe laid under the filter into the valve-well formed in the embankment between the upper and lower filters.

The water is delivered into each filter from a 20-inch main through a 12-inch branch, regulated by a valve, and terminating in a cast-iron trough placed just above the level of the sand, which is by this means protected from scour. Air-pipes 3 inches in diameter are laid in the corners of the filters.

As the spongy iron is here the filtering medium the effective area should be taken about the middle of its depth; so measured each filter has a surface of 90·10 feet square, equal to 8,244 square feet, supposed to be capable of filtering at the rate of 800 gallons per minute, or 140 gallons per 1 square foot for twenty-four hours. The weight of spongy iron employed in all three filters, including a small stock in reserve, is 942 tons, and its value, delivered at Waelhem, £8,000.

The lower or sand filters are of precisely the same dimensions and construction as the upper ones, except that throughout the puddle is only 12 inches thick. The crest of their banks is at + 15·94 feet, and their bottom at + 7·87 feet. On the brick channels rests a layer 12 inches thick of coarse gravel, then 3 inches of fine gravel, and, finally, a layer 2 feet 6 inches thick of Meuse sand. The upper level of the sand is at + 12·14 feet, and as most of the filtration is done close to the surface, the area of that may be taken as the surface of the filter. This is 99 feet square, equal to 9,801 square feet, capable of filtering at the rate

of 800 gallons per minute, or 117 gallons per square foot per twenty-four hours.

In order to regulate the flow from the upper to the lower of each pair of filters, and at the same time to expose the water as much as possible to the air, the 12-inch pipe from the upper filter enters the lower on the side nearest to it, and turning upwards terminates in a sliding bell-mouth overflow fitted with a spreader plate. The overflow is varied in height by a screw and hand wheel, and is adjusted so as to give the proper rate of filtration. It is essential for the water to remain some time in contact with the iron, hence when the filter is clear and free the flow requires to be checked by reducing the head, and, on the other hand, when the filter gets sluggish the head must be increased. The spreader plate is capable of rising and falling on a pair of levers, and has a scale attached to it from which the amount flowing over may be read off. The standard quantity for each filter is 800 gallons per minute. The overflow of the water in a thin sheet exposes a large surface to the air, and appears fully to answer the purpose intended.

The water from the bottoms of the sand filters is taken by 12-inch cast-iron pipes from the centre of the filters to their respective valve-wells, which are common also to the upper filters, and are formed in the bank between them. In each well is arranged a group of valves which connects each filter to a wash-out pipe, and the sand filters to the clear-water main. Both the mains run along the middle bank, the wash-out being connected, at the intake, to the centrifugal pump already described, and the filtered-water main, 15 inches in diameter, terminating in a swivel-pipe inside one of the clear-water tanks. This swivel-pipe is usually adjusted with reference to the level of the water in the sand filters, and prevents their being affected by the varying level in the clear-water tank. The rate of flow from each filter is regulated by the valve in the outlet-pipe, and necessarily follows the uniform rate at which the water enters from the spongy-iron filters. A 5-inch pipe, passing through a Siemens meter, is taken from the main near the engine-house, and is laid between the two sets of filter-beds, thence turns down between the two settling-ponds, and provides water, under from 6 atmospheres to 8 atmospheres pressure, for working the hydraulic cylinders of the intake-sluices and the partial turbine actuating the centrifugal pump.

Pipes 3 inches in diameter, fitted with hydrants and hose, are taken off the 5-inch main, to each of the eight sand-washing tanks

placed beside the filters, and a similar pipe is carried round the settling-ponds, where it is fitted with six hydrants for washing down the slopes.

The sand-washing arrangement consists of eight cast-iron tanks, each 6 feet 11 inches by 12 feet 11 inches by 1 foot 11½ inches deep, having one end fitted with an overflow and sluice. The dirty sand scraped off the surface of the filters is placed in these and scoured by a ⅞ or a 1 inch jet of water playing upon it under a pressure of 6 to 8 atmospheres. The dirty water and mud overflows from the tanks into an open channel in the bank between the sets of filters, and is discharged into a small sand-catching reservoir, whence it flows by the land drains into the river.

A gang of seven men takes one day to scrape off and replace the sand of a filter, and about 33,000 gallons of water are employed in washing it, the cost ranging from 9*d.* to 10½*d.* per cubic yard of sand washed, which includes a charge of 2½*d.* per 1,000 gallons for the water used.

The construction of the filtered-water tanks was a source of great anxiety, Plate 1, Fig. 7. It was necessary to sink them 10 feet below the ground line, and into the waterlogged stratum of fine silt; and, as at times the water in the land would stand nearly level with the surface, while the tanks would often be nearly empty, it was necessary to provide for their being watertight from without inwards, as well as the reverse, and at the same time to make them secure against flotation. It was thought safest to obtain the necessary storage room by making two cast-iron tanks, each 60 feet in diameter by 10 feet deep, containing in the aggregate 340,000 gallons, and connecting them together by a 24-inch pipe.

A bed of concrete 2 feet deep was, with some difficulty, laid on the silt, all over the site of each tank, at − 1·15 foot; on this the tanks, composed of cast-iron plates with planed flanges, were erected, and the ground filled in round them. The bottom of each tank was formed of plates 5 feet square, made sufficiently strong to carry, when supported by the four corners, a column of water 10 feet high. At the intersection of the plate-joints one hundred and one 4-inch columns rose to the level of the top of the tank, and carried on their upper ends eleven rows of cast-iron beams 9½ inches deep, between which 4½-inch brick arches were turned. The spandrels were filled in with concrete, and over all a layer 5 feet 6 inches deep of earth was laid, in order to weight the tanks against the floating power of the land-water. A man-hole pipe and iron ladder rise through the layer of earth in the centre of each tank, and give access to the inside. The tops of the tanks

are 11·16 feet above datum, or about 1 foot above the natural ground line. A 24-inch pipe, governed by a sluice-cock in the engine-room, connects the filtered-water tanks with the sump which runs the whole length of the engine-house, and from which the main pumps draw their water.

In view of the immense importance of having unfailing pumping power in a place like Antwerp, where there can be no extensive high-storage reservoirs, it was resolved to lay out the land at Waelhem so that three complete and independent pumping establishments could ultimately be erected; for the present needs the middle one of the three was to be carried out. The engine-houses were to face the Malines Road, and to be placed parallel to it at a distance of about 40 feet, thus leaving plenty of room for the arrangement of the delivery-pipes, valves, &c., that may hereafter be necessary.

The main engine-room of the part now carried out contains two pairs of compound expansive condensing beam-engines of 170 HP., Plate 2, water lifted. The engines of each pair are coupled together at right angles through a common crank-shaft, and are carefully balanced so that they will creep round at only one and a half revolution per minute, while their maximum speed is twenty-two revolutions. The engines stand upon foundations of brick in native hydraulic lime, and are self-contained and independent of the walls.

Continuous cast-iron bed-plates, secured to the brickwork, carry the cylinders, "A" frames supporting the beam centres and the crank-shafts. The high-pressure cylinders are 18½ inches diameter by 3 feet 8 inches stroke; the low-pressure 30 inches diameter by 5 feet 6 inches stroke. Both the cylinders are steam-jacketed and carefully felted and lagged. Steam at 65 lbs. pressure per square inch is admitted to the high-pressure cylinders by an ordinary slide-valve, with Meyer's variable cut-off motion at the back; and the exhaust steam is conveyed to the low-pressure cylinders by a brass pipe, and distributed by an ordinary single slide. The beams, connecting-rods, and cranks are of cast iron, and the crank-shafts of wrought iron.

There is one main pump fixed in the brickwork, under the cylinder end of each engine. It is of the bucket-and-plunger variety, having a cylinder 22½ inches in diameter by 33 inches stroke, and delivering 47·3 gallons per revolution. The valves are of the ring type, beating in gun-metal seats. The plunger of the pump is actuated by a wrought-iron connecting-rod attached to the back links of the parallel motion. The suction-pipe is

extremely short, and dips direct into the clear-water sump. As there are four discharges into the delivery-main at each revolution, the working is smooth, steady, and noiseless.

Besides the main pumps each engine has its own air- and feed-pump, and, common to each pair of engines, an air-compressing pump for charging the air vessels. The delivery from each pump, 12 inches in diameter, is furnished with a self-acting non-return valve, beyond which the pipes from the pumps of each pair of engines unite by a T into a common 15-inch delivery pipe. This enters into the side of a cast-iron air vessel of 65 cubic feet capacity, placed within the engine-house, and issues again from the bottom to join the 20-inch main to Antwerp. The delivery pipe is also fitted with a self-acting non-return valve just outside the engine-house.

The engines are arranged so that they can be uncoupled and one engine and pump worked by itself.

To facilitate the starting of the engines, and to prevent any undue pressure coming on the pumps from the improper closing of valves, each pump is fitted with a loaded by-pass or safety-valve, the lever of which can be raised by a handle placed near the starting gear of the engine. This arrangement was found most useful when the demand for water was still very small and the engines were running very slowly, because, under those conditions, they would at times stick, or hesitate in their revolutions, and then, by raising the valve and momentarily relieving the pressure on the pumps, the dead point would be got over.

The injection-water is taken from the 24-inch main which connects the settling-ponds to the screw-pumps, and the water from the hot-wells is returned to the same pipe, but at a point a few feet nearer the screws. There is also a supplementary injection from the main, which has to be employed when the screw-pumps happen to be stopped for a short time; because, under these circumstances, the water in the 24-inch pipe soon gets too hot for use.

The feed-water was originally taken from the hot-wells, and forced by pumps attached to the engines through the feed-water heater in the screw-pump annexe into the boilers; but scale formed on the boiler-plates and much mud accumulated, so the arrangement was altered, and the feed is now taken from the filtered water in the main, passed through the heater, and admitted into the boilers without the intervention of feed-pumps. A practical demonstration of the large amount of softening produced by fil-

tration through spongy iron is the circumstance that since the boilers have been fed with filtered water little or no scale has formed.

The engine-house floor is at the level of + 19·69 feet, or 9 feet 6 inches above the ground line. The approach is from the front by a double flight of stairs, underneath which is an entrance to the foundations, the general level of the floor above which is +11·49 feet. The foundations have been so arranged that there is ample access to the pumping and other machinery fixed underneath the engine-room floor, a good light being afforded by windows in the back and front walls.

A 12-ton overhead travelling crane commands the whole of the engine-room.

In front of the starting-gear of each pair of engines is placed a Mather and Platt mercury pressure-gauge connected with the delivery-main, and the attendant's duty is to vary the running of the engines so as to keep a constant pressure. A private telegraph from the head office in Antwerp transmits such information as may be needed to the pumping-station. Each pair of engines is usually run one week at a time without stopping.

In line with the engine-house, and on the right-hand side of it, is the boiler-house. This contains four Cornish multitubular boilers, 23 feet 0½ inch long by 6 feet 6 inches in diameter, each having two furnace flues, 2 feet 6 inches in diameter, terminating in twenty-four 3-inch tubes. The boilers are set in brickwork, with split draught round the sides and return-flue underneath, and are each capable of evaporating 50 cubic feet of water per hour from water at 100° Fahrenheit, under a pressure of 65 lbs. per square inch.

On the left-hand side of the main engine-house, and also in line with it, is the screw-pump annexe, in which are the two screw pumps and their horizontal engines, already described, a 10-inch centrifugal pump and engine as a stand-by, a line of wall shafting, and a few tools necessary for small repairs.

The 20-inch main to Antwerp runs parallel to the face of the engine-house, and turns off into the main road just beyond it, passing first through the bottom of an air-vessel, 4 feet 6 inches in diameter, and 20 feet high, having a capacity of 292 cubic feet. The air-vessel is fitted with a pressure-gauge and a glass water-gauge, to which is attached a scale indicating the proper level of the water for any given pressure. The object of this is to prevent air getting into the main, as it would do supposing the air-vessel full of air at say 7 atmospheres, and the pressure were to fall to

6 atmospheres. The lowest pressure has been assumed to be that of the town, namely, 5 atmospheres. The supply of air is kept up by the compressing pump fitted to each pair of engines, and a cock is provided to allow excess of air to be blown out.

On account of the severe cold sometimes experienced, the air-vessel, the sliding overflows in the sand-filters, and the valve-gear at the intake, have to be enclosed in suitable houses, heated by stoves.

The chimney is 3 feet $1\frac{1}{2}$ inch square inside by 80 feet high.

The foundations of the machinery and buildings were a source of great anxiety. The excavations for the sump under the main pumps, and those for the screw-pumps which had to be carried 3 feet 6 inches below datum, or nearly 14 feet below the ground level, could only be accomplished after surrounding the sites with 4-inch sheeting piles bird's-mouthed to each other and driven as close and watertight as possible. The whole of the buildings and chimney stand upon a platform of round fir piles, 26 feet long and 12 inches in diameter at their upper ends, sunk 23 feet into the ground. The piles were driven by an ordinary engine worked by steam-power, having a monkey weighing 1 ton, falling on an average 8 feet. The last 3 feet 3 inches of driving took on an average thirty blows, and the last two or three blows sunk the piles $\frac{3}{8}$ inch each blow. On to the heads of the piles 12-inch square timbers were tenoned, and across these, similar timbers were laid, notched in a little and spiked. The ground was cleared out about the piles to the depth of 3 feet 3 inches, and filled in with a layer of concrete of the same thickness, finishing flush with the top of the wood-work. There are in all four hundred and twenty piles under the engine, boiler, and screw-house, and twenty-five piles under the chimney. The concrete was composed of 3 parts of small stones, 3 parts of brickbats, 4 parts of lime, 1 part of sand, and 1 part of trass. The lime, trass and sand were mixed in a mortar-mill, and worked up with the bricks and stones afterwards. The mortar used throughout was composed of 3 parts of lime, 2 parts of sand, and 1 part of trass. Like the concrete the mortar sets rather slowly, but when set it is very hard, tenacious, and possesses decided hydraulic properties.

The bricks used in Belgium are small, $7\frac{7}{8}$ inches by $3\frac{15}{16}$ inches by $1\frac{15}{16}$ inch, and a great deal of mortar is used in laying them; but thanks to its excellent quality they make very sound work, as may be gathered from the circumstance that no stone whatever was used, or thought necessary, in the foundations and setting of the machinery.

The river Nethe being navigable for good-sized coasting vessels

afforded great facilities for bringing machinery and materials to the works. A 5-ton derrick crane was erected on a wharf close by the high road, and the machinery, loaded into small vessels at the Erith Ironworks, came alongside at Waelhem and was discharged without difficulty.

The contractors for the masonry and earthworks erected a substantial wharf on the land occupied by the works, set up light cranes, and laid down a system of tramways which greatly expedited and cheapened the work. Their wharf and tramways were, after the completion of the contract, put in substantial repair and purchased by the waterworks company, and are found very useful in landing coal and filtering materials. A coal and spongy-iron store have also been constructed, the former being connected by a tram with the boiler-house. Weighing-machines have been fixed on the wharf and at the boiler-house for keeping a rigid check on the receipt and consumption of fuel, sand, and other stores.

The earthwork and masonry were executed by Messrs. Poiry and Simon Brothers of Antwerp, of whose skill and energy it is difficult to speak too highly. The hazardous works connected with the foundations were done at a schedule of prices; the works more susceptible of certain calculations were taken at a fixed price. The whole of the work was carried out under the direction and chief superintendence of Mr. T. P. Wilson, Assoc. M. Inst. C.E., Resident Engineer at Antwerp, assisted by Mr. E. Devonshire, Stud. Inst. C.E., resident at Waelhem. To the zeal and intelligence of these gentlemen is due much of the credit connected with the rapid and successful execution of important and often hazardous work.

The result of eighteen months' constant running has to a great extent confirmed the expectations formed respecting the spongy-iron system of filtration. The water has varied but little in brightness or in quality, and the beds of spongy iron and gravel seem to be nearly unaltered. Dr. Frankland[1] visited the works in June 1882, after they had been in operation for a year, and summarises his report on the water by the statement:—"Taking into account the extremely bad quality of the raw material at the time of my visit, I consider this result to be eminently satisfactory from a purely chemical point of view; but there is another factor involved in the result which has still greater weight with me in the comparison of the water before and after treatment, viz., the circumstance that the water has been passed through a material which is absolutely fatal to bacteria and their germs."

[1] Report of Dr. Frankland to the Directors of the Spongy-Iron Water and Sewage Purifying Company upon the Antwerp filter beds, August 1882.

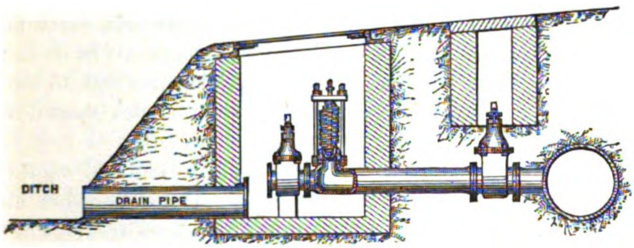
The quantity of suspended matter in the water renders it necessary to scrape off and wash the top layer of sand in the higher filters about once in every six to nine days, and the whole of the sand will have to be washed about once a year. The upper layer of the spongy iron, some 6 inches deep, appears to require loosening or breaking up about once in six months.

The deposit in the settling-ponds is much less than was expected, and probably cleaning out once a year will be sufficient. The lower or sand filters last longer than the iron filters, and will probably need cleaning out only half as often. The adoption of the spongy-iron process involved very little extra expense beyond the capital outlay necessary to raise half the filters to a higher level, and to provide the spongy iron itself. The aggregate filter area would be the same as for ordinary sand filtration, because the rate of percolation is double in the system described compared to what it is in ordinary filters. In both cases the absolute rate of filtration, and the frequency with which the sand-surfaces have to be scraped and washed, depends upon the nature of the water; at Waelhem this is, unfortunately, exceptionally bad. The pumping from the settling ponds on to the filter beds was inevitable in any case, but, for the system adopted, the lift is about 4 feet more than would otherwise have been necessary. The only extra working expense is the periodical breaking up and perhaps washing of the upper layer of spongy iron at a cost of about £14 each filter, and the renewal of exhausted material; but of the requirements under the last head there is as yet no experience beyond this, that eighteen months' use does not seem to have sensibly wasted or injured it.

The 20-inch main to Antwerp is laid, for the most part, under one of the unpaved margins of the high road; it passes through the town of Contich, runs through the ditch and ramparts of the fortifications, and by the suburb of Berchem up to the Pépinière, where it bifurcates into an 18-inch pipe and a 16-inch pipe. The total length is 10 miles. The main is laid in dense fine dry sand, and is buried to a depth of 3 feet over the sockets. At Waelhem the top of the pipe is 13 feet above datum; it rises to a maximum elevation of + 95 feet in 1½ mile, then falls to + 60 feet at 2¾ miles, rises again to + 76 feet at 3¾ miles, passes through Contich at + 70 feet, dips under a culvert + 53 feet at 5¼ miles, rises to + 76 feet at 6 miles, and drops with gentle undulations to + 35 feet at the fortifications, where, in the wet ditch, it reaches a minimum of + 16 feet, rises inside the ramparts to + 37 feet, and terminates at the Pépinière at + 29 feet. At the Waelhem end,

at $2\frac{3}{4}$ miles, $5\frac{1}{2}$ miles, 9 miles, and 10 miles, sluice-cocks are fixed; at each of the seven crests automatic air-valves are arranged, and at four depressions wash-out branches and spring safety-valves are fixed. The safety-valves and wash-outs are shown in detail in Fig. 1. The arrangement is believed to be novel; at any rate it

FIG. 1.



RELIEF-VALVE AND WASH-OUT.

is efficient in protecting the main against sudden shocks caused by the too rapid closing of sluices, or the escape of water confined by air-locks. The relief valves are loaded to a little above the maximum working pressure, and the circumstance that they frequently blow, and that only two bursts have occurred since the main was fitted, proves their utility. They are kept in working order, and tried periodically by the man in charge of the main. Neither Contich nor Berchem has as yet made any arrangement for taking the water, so that, although suitable branches are placed in the main, no distribution-pipes have been laid. At the wet ditch of the fortifications, which is 160 feet wide, the socket-pipes are changed to 20-inch extra strong flange-pipes with faced flanges. A trench was dredged across the bottom of the ditch and levelled with the aid of a diver. The water was lowered 3 feet, and the eleven lengths of flange-pipe with their terminal bends were put together on one of the banks, severely tested, blank flanges fitted to the open ends, and baulks of timber, sufficient to float the weight, attached along their whole lengths. The water was next allowed to rise till the pipes floated; they were towed over the trench, additional rising lengths bolted on to each extremity; the ends were then supported by tackle attached to sheer legs, the flotation was reduced sufficiently, by the removal of portions of the raft, to enable the pipes to sink, and they were then safely lowered on to the bed prepared for them. The final bedding and removal of timber and tackle was accomplished by divers.

The 18-inch and 16-inch branches, into which the 20-inch pipe

divides, run together down the Chaussée de Malines till they reach the Boulevards, where change-cocks are introduced. The 16-inch main branches to the right in a north-easterly direction to the Place de la Commune, where it divides into a 12-inch pipe running eastward towards Borgerhout, and a similar pipe taking a northerly direction down the Avenue de Commerce towards the docks. The 18-inch main is reduced to a 16-inch beyond the change-valves, and proceeds in a northerly direction down the Rue Léopold to the east of the Cathedral, where it is reduced to 12 inches in diameter. A 12-inch pipe branches out to the westward of the change-valves in the Boulevards, and runs down the Avenue de l'Industrie towards the Quartier Sud.

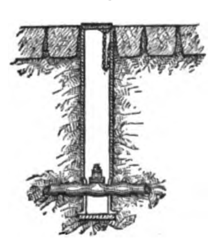
The distribution-pipes throughout the City are laid on a system which, as far as possible, keeps up a constant circulation through them, and permits a range of pipes to be shut off without stopping the supply of the neighbouring streets, and even often enables the service to be kept up when portions of one of the mains or larger pipes have to be shut off. An additional advantage is that, in case of fire, stronger jets can be worked, because the water will flow to the hydrants by more than one set of pipes. As far as practicable, each sub-district is under the control of two terminal cocks only, but in a few cases it is necessary to close three, and even four cocks, to enable certain streets to be entirely shut off from connection with the mains. All pipes with dead ends terminate in hydrants, which have to be opened periodically to prevent the water stagnating; but the advantage of keeping up a constant circulation is so great that the blank ends are being coupled up to other pipes at every available opportunity. The distribution pipes vary from 9 inches to 3 inches in diameter, the latter being the smallest size. Generally one pipe only is laid down a street, but in a few wide streets, such as the Place de Mer, Marché aux Chevaux, and the Boulevards, pipes are laid on both sides.

To avoid the necessity of repairing defective pipes and joints after the opening of the works, a duplex steam-pump, capable of delivering 100 gallons per minute, under a pressure of 240 feet, was fixed in the Rue Jacob and at Waelhem, and by means of these the 20-inch main and the subsidiary mains and service pipes in the streets were tested as fast as they were laid. The duplex pump has no fly-wheel, and gives a maximum pressure depending only on the pressure of the steam in the boiler; it is automatic in its movements, that is to say, if the flow of water from it is stopped the pump stops, and yet starts again the moment the least escape of water takes place. The duplex pumps, therefore, formed an excellent gauge of the condition of the pipes. As soon as a new

section was turned on, the pumps would run off at full speed till the pipes were full. If the joints were all good, and the pipes sound, the pump would come nearly to a standstill, and remain so for hours, keeping up a maximum pressure. If, however, there was any defect, the pump ran at a speed proportional to the leak, and by that means gave the engineers an accurate idea of its extent. By shutting off various sections in succession, and by using pressure gauges at the hydrants, the leaks could, as a rule, be easily found. The mains and service pipes in the City are laid, for the most part, in sandy soil, with a depth of about 2 feet above the sockets. This, at Antwerp, is considered sufficient protection from frost. In many parts of the old town considerable difficulty was experienced in laying the pipes through and past old cellars and culverts, and in the newer parts the relics of the old fortifications gave a good deal of trouble, in both instances chiefly from the unequal support the pipes received; most of the breakages which have occurred are attributable to this cause. The joints throughout were made in the ordinary way, with yarn and lead. The total length of subsidiary mains and service pipes is 84 miles. Pressure throughout the town is maintained at 5 atmospheres, or 170 feet.

The supply for street-watering and fire-service is provided for, by means of seventeen hundred ball hydrants. As is usually the case, water for the extinction of fires is given gratis, but that used in street watering is measured by Siemens meters, fixed in portable stand-pipes, which are used either in filling the water-carts or in irrigating by travelling pipes. The supply to the shipping is measured in the same manner. The service-pipes for private houses are all lead, and vary from ½ inch to ¾ inch in diameter. The pipes for public establishments and manufacturers range from 1 inch to 3 inches, the larger sizes being of cast iron. A stop-cock, of specially strong make, is fixed in the street for each service (Fig. 2), and is protected and made accessible by a cast-iron cover, so arranged that it can be fixed by the pipe-layers without the use of brickwork. This system allows free access to the service pipes, without the necessity of pulling up the streets or entering the houses, and also compels the pipes to be laid at a proper depth below the surface. Most of the services are laid in by Upward's apparatus, without emptying the pipes or even taking the pressure off.

Fig. 2.



Service-cock.

The terms of the concession permit every consumer to demand a supply by meter, and at first it was thought that the inhabitants would adopt that method. In prac-

tice, however, it is found that most of the householders prefer to make special agreements for an annual rate, which saves much capital, outlay, and trouble.

The greater part of the 20-inch main and pipes within the City were supplied by Messrs. Jahiet, Gorand, Lamotte, and Company, of Ottange, in Loraine, but some came from Messrs. Cochrane and Company, of Middlesbrough. The Ottange foundry enjoys a very high reputation on the Continent. The metal used is smelted from ore raised at the works; it is mixed with some Cleveland pig, and produces a very tough close-grained iron, from which, with perfect appliances for vertical moulding, excellent pipes, of uniform thickness, are produced. The relative cost of English and German pipes was naturally an important consideration.

The following Table gives some interesting comparative figures:

	German Pipes. 19¼ in. in diameter.	English Pipes. 20 in. in diameter.
Length of pipe exclusive of socket . .	13·1 feet.	12·0 feet.
Thickness of metal	0·65 inch.	0·75 inch.
Weight per lineal yard	3·67 cwt.	4·50 cwt.
" " " of 20-inch pipe	3·78 "	
Test pressure	850 feet.	450 feet.
Price per ton delivered in Antwerp .	£7 2*s*. 6*d*.	£6 11*s*. 0*d*.
" lineal yard	£1 6*s*. 2*d*.	£1 9*s*. 6*d*.
" yard of 20-inch pipe . . .	£1 6*s*. 6*d*.	

Thus it would appear that with the German pipes there was a saving of 11 per cent. in the number of joints, of 8½ per cent. in weight, and of 10 per cent. in cost, even when reduced to the same diameter as the English pipes. The 20-inch main was subjected by the Municipal Engineer, Mr. Royers, to a protracted test under 8 atmospheres, or 272 feet.

The pipes in the City were, for the most part, laid under a contract by Mr. R. K. Croskey, who carried out the work in a very satisfactory manner. Mr. T. P. Wilson, the resident engineer-in-chief, assisted by Mr. C. A. Friend, had charge of this portion of the undertaking. The works, which had been executed in fifteen months, were finally opened on the 21st of June, 1881, by the Burgomaster, Mr. Leopold de Wael, and members of the Municipal Council. The cost of the undertaking was £280,000.

The Paper is illustrated by several drawings, from which Plates 1 and 2 and the woodcuts in the text have been prepared.

Discussion.

Mr. Anderson.

Mr. ANDERSON directed attention to a sample of water from the Nethe, together with samples from the spongy-iron filter and of the water delivered to the town; also of the same water, taken in November, 1881, which appeared to have undergone no change. He likewise exhibited mixtures of spongy iron and gravel used in the filters, and of the spongy iron itself.

Dr. Frankland.

Dr. FRANKLAND said he had visited the filters in June last. With reference to the property which spongy iron possessed of destroying bacteria and those lower organisms which were now regarded as the great pests of drinking water, engineers had, for many years, been troubled by the chemists who insisted upon greater and greater degrees of purity in drinking water. For a long time it was considered sufficient if the water was delivered in a clear, transparent and tolerably colourless condition, so that the eye should not find fault with it; but modern investigation showed that such clear and transparent water was sometimes charged with material fatal to the water-drinker. As research proceeded, it was found that this material consisted of organised matter as distinguished from organic matter merely. From the researches of Pasteur, Tyndall, and others, he believed no doubt was now left in the minds of biologists that zymotic diseases were produced by the introduction into the system, and the enormous reproduction there, of low organisms, and that these low organisms in many cases found their way out of the system by the alvine evacuations of the patient. The morbific matter was so subtle that it was impossible to separate it from water by any sort of filtration that could be brought to bear upon it. It was therefore of great importance to discover some material which was capable of destroying these organisms. The tenacity of life exhibited by the different forms of bacteria, of which the peculiar species producing zymotic diseases were varieties, offered a formidable difficulty to the solution of the problem. He had had, in his laboratory, a number of experiments made upon that subject by a pupil of his, Mr. Frank Hatton, who introduced liquids containing bacteria — such liquids as mutton-broth which had become putrid—into vessels filled with mercury and into which, afterwards, gases of various kinds could be introduced. He found that the bacteria were exceedingly lively under an atmosphere of pure oxygen; that they enjoyed themselves apparently equally

Dr. Frankland. well in an atmosphere of carbonic acid, and they were quite lively in nitrogen; that they did not look much depressed in sulphurous acid; that they got a little dull when put under cyanogen, but in a few days recovered, even from that, and became nearly as lively as ever; but when they were brought into contact with a solution of carbolic acid of a certain strength, they immediately ceased to move and to live. The same effect was also produced by spongy iron; by a short contact with that substance the bacteria became lifeless forms. This was an exceedingly valuable property of spongy iron, and it was discovered by Mr. Bischof before the experiments to which he had alluded had been made. It was discovered by treating fresh meat with water that had been in contact with spongy iron. It was found that the meat would not become putrid for a long time after it was in contact with water so treated, provided the water and the meat were preserved from contact with the atmosphere. That result proved conclusively that the living bacteria, or their germs, that were certainly always present in water exposed to air, were destroyed by contact with spongy iron. It should be borne in mind, however, that the bacteria thus experimented on were the ordinary bacteria developed in putrefaction, and not the bacteria capable of communicating to man the diseases of which he had been speaking. It would, therefore, be premature to assert positively that spongy iron would destroy those other forms; but inasmuch as all the known forms of bacteria behaved much in the same way under such agents as spongy iron, sulphurous acid, and carbolic acid, he thought it probable that the harmful bacteria were likewise destroyed by spongy iron. This was the only substance known at the present time, applicable to water, that would destroy the known forms of bacterial life. It was, therefore, of great importance that spongy-iron filtration should be tried in various localities where competent observers might have an opportunity of noticing any effect that might be produced in the diminution of zymotic diseases amongst persons who drank the water that had been so treated. Spongy iron, however, did more than remove the organisms; it removed the organic matter in solution very effectually. In that respect it was about equal to animal charcoal, which, for a time, attracted great attention on account of the property it possessed of abstracting dissolved organic matter from water. But, unfortunately, animal charcoal had precisely the opposite quality with regard to bacterial life to that possessed by spongy iron. It favoured the development and growth of low organisms, and, after it had been in use some months, the water

issuing from a filter containing animal charcoal would be found charged with minute anelids which were visible to the naked eye. Any substance containing phosphorus favoured the development of that kind of organic life to a great extent. It was, therefore, desirable that the attention of engineers should be prominently directed to the trial of spongy iron as a safeguard against the propagation of epidemic disease through water, and especially should it be tried in cases where there could be no doubt that sewage found its way, to some extent, into the water-supply which was being distributed. Dr. Frankland.

Mr. W. Atkinson said that no chemical theory, as to the abstraction of carbonate of lime, was given in the Paper, and asked if Dr. Frankland would state his views on that subject. Mr. Atkinson.

Dr. Frankland replied that he had for many years used a domestic filter of that kind. With regard to the general question he might state that throughout the entire use of the filter, until it was finally blocked up and would not permit the water to pass, it softened Thames water exactly one-half. The property of abstracting organic matter from water went on unabated so long as the water would pass through the filter, so that there need be no fear of the filter getting useless whilst it continued to act. Dr. Frankland.

Mr. C. Ekin observed that it would be very interesting if some more rigorous comparison were made between the effects of spongy iron and of sand. In the Paper there was a description of the combined influence of the two, as well as of the great care in collecting the water. If, as had been suggested, future experiments were made on a large scale, it might be well to try what would be the influence of mere sand as against spongy iron, using the same precautions in both cases. There was also the influence of precipitation to be considered. The water containing iron was exposed to the air and oxidised, and the oxide of iron was precipitated, and carried with it some organic matter, in the same way that in Clark's softening process the precipitated carbonate of lime carried down with it organic matter, and so purified the water. The Author had stated that the water that had passed through the spongy-iron filter left much less scale in the boilers than the water that had not, and Dr. Frankland also stated that he has found a domestic filter soften Thames water to the extent of one-half. If on the large scale, as with the waterworks of a large city like Antwerp, the spongy iron really removed one-half the mineral matter dissolved in the water, supposing the water to be of ordinary hardness, the removed matter would amount to tons in a comparatively short time, and must inevitably block up the Mr. Ekin.

Mr. Ekin. filter. Dr. Frankland also observed that, as long as a domestic spongy-iron filter acted, water would come through pure as regarded organic matter, but it must be remembered that a filter acted by keeping back organic matter which would accumulate in the filter to an extent dependent on the impurity of the water; and in any case there must come a time when the filter would contain so much organic matter as actually to add impurity rather than remove it, and so the last state of the water might be worse than the first. This was well known to take place with animal charcoal filters, and the charcoal had to be either reburnt or fresh charcoal substituted, and some renovating process of the sort must be necessary in the case of spongy iron, supposing it did the work claimed for it. He would not go into the vexed question of bacteria. It was pretty well recognised that organised life was at the bottom of all diseases, but the actual organism had not yet been detected; so that the mere fact of spongy iron being inimical to bacterial life was not positive proof that it would also destroy the morbific matter that created disease. Charcoal would not do it, and it might be inferred, reasoning from analogy, that spongy iron would not. At present spongy iron was only on its trial, and more definite results were required before it would be possible to speak positively on the subject.

Mr. Homersham. Mr. S. C. Homersham said he agreed with Mr. Ekin. A paper had been read by Dr. Angus Smith, an admittedly high authority, before the Literary and Philosophical Society of Manchester, on the 17th of October, 1882, "Notes on the Development of Living Germs in Water," in which, alluding to a new process invented by the German chemist Koch, who had introduced a weak solution of gelatine into water for the better enabling a microscopical examination to be made, Dr. Smith gave an account of examinations of several specimens of Manchester water which he had tried by the new process. That water was very pure as far as mineral matter went, but it generally contained peat and living organisms. After filtration through spongy iron, the following was the result: "After two days a few white spots appeared; after three or four, small spheres appeared, containing living bacteria; after four days the spheres enlarged, and a deposit formed at the bottom very full of bacteria." Mr. Homersham considered this to show that no reliance could be placed on filtration through spongy iron as advocated for killing bacteria or other organisms. For himself, he did not believe that water as bad as that described in the Paper, when passed through a filter bed containing spongy iron would be wholesome, or free from

germs or living organisms. Water-logged filter beds were not able to free water from living organisms. The question was an important one, and he hoped it would be followed up. Any one could get some of the water as supplied to Antwerp, and examinations could be made by competent microscopists. When the results were known he could but feel that they would show reliance ought not to be placed on such water passed through a filter bed containing spongy iron as described in the Paper. Mr. Homersham.

Mr. J. HENDERSON PORTER asked Dr. Frankland, who had stated that spongy iron had the effect of softening Thames water one half, what became of the carbonate of lime that was necessarily precipitated by the process? The accumulation of carbonate of lime might not seriously affect a house filter, but he could not understand what could be done with it when it was deposited on a large scale. In softening water by Clark's process there were, of course, two precipitates—lime throwing out lime as a separation in the bicarbonate of lime took place. That separation might be observed also when the London water, for example, was boiled in a flask. The precipitation would surely have some clogging effect upon the spongy iron, which, he thought, must impair its power of filtration. Mr. Porter.

Dr. FRANKLAND replied that there could be no doubt that carbonate of lime was precipitated amongst the spongy iron. His remarks applied to a domestic filter, which was blocked up in about a couple of years, and probably that blocking up was due in part, at all events, to the carbonate of lime so deposited. Dr. Frankland.

Mr. W. B. BRYAN observed that it was impossible to overrate the importance of efficient filtration, but he should be glad if Mr. Anderson would give some statistics as to the cost per 1,000 gallons, or per cubic metre, of maintaining and cleansing the spongy-iron filters. It was true they had only been in operation about eighteen months, a period too short to give reliable results as to cost for maintenance, but it appeared to him that it would be rather expensive to have to remove the whole of the sand lying upon the spongy iron in order to break up 6 or 8 inches depth thereof every six months. The maintenance of filters was a very great annual item with the London Water Companies, costing roughly from $\frac{1}{20}d.$ to $\frac{1}{10}d.$ per 1,000 gallons. He should also like to see a comparison between the cost of constructing spongy-iron filters, and those as used by the London Water Companies. As to the softening of water by spongy iron, he could give no opinion. Mr. Anderson had said that the feed-water for the boilers was originally taken from the hot wells, and he found Mr. Bryan.

Mr. Bryan. that a considerable quantity of scale was caused; a practical demonstration of the large amount of softening produced by filtration was the circumstance that, when the boilers were fed direct from the pressure main by filtered water, little or no scale had been formed. At the East London Water Works one set of engines and boilers was fed from the hot-well, and a considerable amount of very hard scale was formed. The water was filtered. The same water was used for other boilers 50 or 60 yards away. Instead of passing from the hot-well, it passed direct from the pressure-main into the boilers, as at Antwerp. The effect was the same as that described in the Paper. When the water was taken from the hot-well, very hard scale was deposited in the boilers, and when it was taken direct from the pressure-main there was no scale, but a considerable amount of soft deposit. Before the system of spongy-iron filtration could be recommended extensively, it would be necessary that experiments should be carried on for a considerable length of time, in order to ascertain not only the first cost, but the annual maintenance. Its adoption would entail an enormous capital expenditure in order to filter 140 or 150 million gallons daily for the inhabitants of London, and such an outlay would have a very appreciable effect upon the dividends of the various companies for some time to come. With regard to the percussion valve, he might mention that he had found by experience that in a long main, instead of having a weighted valve, or a valve with a powerful spring on the top, it was better to have one with two faces, maintaining equilibrium by a slight weight. In case of a burst, followed by the quick closing of a valve, the concussion was much lessened.

Mr. Latham. Mr. Baldwin Latham asked if the Author or Dr. Frankland would supply an analysis of the water before and after treatment. He had not had much experience in the use of spongy iron, except in domestic filters, but he had used Spencer's magnetic oxide of iron in filters, for town supply, and previously to adopting this material he had made a series of experiments with domestic filters constructed of this material, and the results were very satisfactory. For many years the water of the River Calder supplied to Wakefield had been filtered through Spencer's material with most satisfactory results. It would be difficult to find a town in this country drawing a water-supply from such an impure source as that at Wakefield; but after undergoing the process of filtration, the water was to all appearances satisfactory, and the town had a death-rate from zymotic and general causes lower than that of Halifax and Dewsbury, both of which were located upon the

same river and at a higher level, and both drew their supply from impounding reservoirs. His experience was that iron in either form was effectual in purifying water. The magnetic-oxide of iron, however, was always mixed with sand. It was a mistake, in his opinion, to mix such substances with a coarse material, because there was a great liability of the water not coming into contact with the purifying medium. If a perfect mixture took place with a material like sand, and a porous material like spongy iron, the water would naturally follow the spongy iron, but if the spongy iron was mixed with very coarse gravel, which had no effect whatever in purifying, the water might pass without proper contact with the iron. Mr. Latham

Mr. SCHÖNHEYDER thought that the mode described in the Paper, of warming the water to prevent the filter-beds freezing, was a wasteful one. He should have thought that, if the frost lasted any length of time, it would be better to lead the steam from the low-pressure cylinder into some kind of surface condenser, so as to get the heat effected free of cost. Of course it would depend upon the length of time the frost lasted whether such a plan would be economical or not. Mr. Schönheyder.

Mr. J. A. WANKLYN said it had been stated that a spongy-iron filter had not lost its power after the carbonate of lime had been deposited in its pores, and he had no doubt that was true. It was well known that a great number of porous substances had the peculiar property of removing organic matter from water, which was done by a kind of oxidation. He believed that spongy iron was a very effective filter, but he did not believe that it had any advantage over sand. Mr. Wanklyn.

Mr. W. W. BEAUMONT asked Mr. Latham to give the cost of filtration by means of magnetic-oxide of iron, so as to compare it with that by the spongy-iron system. Mr. Beaumont

Mr. BALDWIN LATHAM said he had not gone into that question, but the material he tried some years ago cost £5 a ton. It was mixed in the proportion of 1 part of magnetic-oxide of iron to 1 part of sand; but on the top of the filter sand was used again, and there had not been to his knowledge any occasion to renew the magnetic-oxide of iron. Mr. Latham.

Mr. E. K. BURSTAL thought it would be a great advantage to have a comparison of the cost of cleaning sand filters, and filters with sand and spongy iron combined. He was not able to supply any information with regard to spongy iron; but with regard to sand filters, he could state, from his experience in Derby, that the cost of cleaning varied very much with the construction of the Mr. Burstal.

Mr. Burstal. filters. In the old filter-beds the sand-washer was placed outside the filter-beds, and therefore the sand had to be wheeled from them to the sand-washer. With the new filter-beds the sand-washer was placed by Mr. Hawksley in the middle of the filter-beds. In the old beds the cost of cleaning was 2*s.* 1·6*d.* per cubic yard of sand washed, or 0·782*d.* per square yard of filter-bed area. With the new filter-beds the cost was 1*s.* 2·9*d.* per cubic yard of sand washed, or 0·392*d.* per square yard of filter-bed, or exactly one half the other. The figures had been taken over some months of ordinary every-day working. The cost of spongy iron was said to be about 54*s.* per square yard of filter-bed area. Taking the cost of filter-beds at 30*s.* per square yard—5*s.* for the material, and 25*s.* for the construction—the addition of 54*s.* for spongy iron was very considerable, and would be only justified by some great chemical advantage. If spongy iron reduced water of 16° or 18° of hardness to half that amount, there must be a large deposit of carbonate of lime; and, taking the sand to be 2 feet thick above the gravel, it appeared to him that a very great expense must be incurred before long in removing the spongy iron and washing the carbonate of lime out of it. The domestic filter got choked, and he assumed the other would be also. It would be interesting to know how many gallons of water had passed through the Antwerp filters, in order that it might be seen whether they had been working to their intended capacity. With reference to protection against frost, he did not think it had ever been found necessary in England to have any heating of the water. On some of the most exposed districts in Lancashire, where he had been engaged on waterworks, he had never seen properly treated filter-beds affected by frost. Of course, if there was any water in the filter, and it was not at work, some inconvenience might be caused; but that would be owing to carelessness. In England during frosts there was so much difficulty in affording an adequate supply of water that there was no time for the water in the filters to freeze. If in new works like those at Antwerp, the system of supply and fittings was so good that any waste could be checked in winter, and the pipes protected in such a way that there was no inducement to people to waste the water, it might perhaps be necessary to protect the filter; but he thought that it could be done in a cheaper manner than by injecting steam.

Mr. Anderson. Mr. Anderson in reply to Mr. Baldwin Latham's request supplied the following information:—

ANTWERP WATERWORKS. ANALYSES of WATER EXPRESSED in PARTS per 100,000. Mr. Anderson.

Description.	Total Solid Matters.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Total combined Nitrogen.	Chlorine	Hardness.		
							Temporary.	Permanent.	Total.
River-water after subsidence for 23½ hours	21·00	0·623	0·219	0·028	0·242	1·8	4·6	6·8	11·5
After filtration through spongy iron and sand	12·32	0·244	0·055	0·000	0·055	1·8	4·0	4·4	8·4

There were no traces of nitrogen as nitrates and nitrites, or of previous sewage or animal contamination, in either description of water; but while the river-water of the subsidence still continued turbid, after filtration through spongy iron and sand it was clear.

Mr. W. ATKINSON said that the Author had drawn attention to the special form of foundation adopted. Without challenging its appropriateness, he desired to avail himself of the opportunity of bringing before the members another form which he had used ten years ago. It was in a rather difficult position, but it had stood perfectly, and had earned the character of being a thoroughly reliable form of construction. The piles were arranged as in the Author's design; but, instead of bracing them together by timber, Portland-cement concrete had been used. The first foot was Portland-cement concrete; just below that the ground had been taken out and punned with broken stone or gravel; after that there were 2 feet depth of blue-lias concrete. The advantage was that the timber was a great deal lower in the ground, and therefore less exposed to the influence of drought. As the building had a frontage of 200 feet, and a total length of wall of 430 feet, and also twenty-three columns and four hundred piles were used, it was a test of the formula on a sufficiently large scale. The weight on the piles supporting the walls was 7·5 tons, and on the piles supporting some of the columns 11 tons. Experiments were made with trial piles, and the proper size and length then estimated; but with shorter piles a greater bearing power was obtained owing to the compression of the ground. Thus the actual bearing power of the piles was about 15 tons each for the walls against the 7·5 tons required, and for the columns about 14 tons in place of 11 tons. Referring to vol. xxvii. of the Minutes of Proceedings at 275 and subsequent pages, it would be found that doubts existed as to the applicability of any formula, thus practical results tested Mr. Atkinson.

Mr. Atkinson. by time were valuable. The formula was that of Major Sanders, U.S. Engineers:—

$$\frac{f \times w}{p \times 8} = x = \text{safe load in tons.}$$

f = fall of monkey in feet.

w = weight of monkey in tons.

p = penetration of pile in feet.

which should be the average of some five of the last blow.

In the case above referred to the monkeys weighed from 14 to 20 cwt., and the final falls were from 9 to 11 feet. This work had stood for ten years without any sign of a crack. It was built in continuation of an old structure, and tied into it, so that if there had been a slight subsidence at that point it would have been detected. The piles varied from 10 to 17 feet. Each day as the driving was carried on the calculations were made, and the piles were varied according to the amount of resistance found to exist in the ground. He had carried out the same plan in a building, one end of which rested on solid chalk, and the other stood on piles 30 feet long in a river; and that building also had proved stable. Reference had been made in the Paper to the pressure-gauge on the rising-main. Engineers used that to calculate the power developed in the engines; they took a great deal of pains to estimate the HP. as indicated in the cylinders, and then they estimated roughly the work done. There were two considerations, not, indeed, of much practical moment, but of scientific interest, connected with the pressure-gauge. In the first place, it did not give any knowledge of what occurred behind, of the kinetic energy existing in the water. When pumping was carried on at a low speed that was of small moment, but sometimes pumping was effected at the rate of 5 feet per second. As the energy put into the water varied as the square of the velocity, it became a matter of some practical importance, and it was of very great moment when the lifts were small. Of course when the lifts were high, it was a small percentage; but if a man had taken pains in the construction of the engine, and had got some one to indicate it, and calculate minutely the power, then, in taking the work done in pumping, the kinetic energy should be estimated as it amounted to about 25 foot-lbs. for each cubic foot of water moving 5 feet per second; suppose the kinetic energy represented only 1 per cent., and that it was omitted in the calculation, and then taking a loss of 10 per cent. in the engine, there would remain 90 per cent. of effective work. If it could be raised to 91 per cent., adding the 1 per cent. of kinetic energy, it was quite clear that the loss in

the engine, instead of being 10 per cent., would be 9 per cent.; therefore the engine would give 10 per cent. better results than had been calculated. Then it was assumed that the pressure-gauge gave the statical pressure, plus the resistance of the mains; but in that case the effect of the fluid friction was left out. The experiment was an easy one. If a little pipe were put into the side of another pipe, and connected by an india-rubber tube with a glass gauge, it would be seen that the moment motion commenced in the pipe the gauge fell. It would be interesting to know whether makers took any special precaution with regard to the mode in which the pipe was attached, and whether they had any cognizance of what the depression amounted to. It could be easily ascertained, thus: taking a pipe of good length, and dividing the length into two, the pressure-gauge could be put on the bottom, and an exactly similar gauge half way up. Those two being equally affected by the fluid friction, the difference between them would give the true statical pressure, and the friction for one half of the pipe; and loss of pressure due to fluid friction would be the above difference minus the pressure on the upper gauge. The question had been raised as to whether there would be any deposit of carbonate of lime in the spongy-iron filters; but, before referring to that point, he would allude to the material itself. He had taken a specimen, and found that it was about 4·4 specific gravity. It was called ferrous oxide; some of it being oxide, and a portion of it metallic iron. The proportion of iron to oxygen in the specimen was about 80 per cent. of the former to 20 per cent. of the latter. It was placed in a filter-bed, and if two or three conditions were assumed, it would be seen where the whole operation lay. If perfectly pure water were introduced without any mixture of oxygen, it would be admitted that the iron would remain as it was. It would hardly be assumed that it split up the water. If it did ferric oxide would be produced, and both it and the ferrous oxide might be assumed to be insoluble under the ordinary conditions of water, but it would certainly take up all the free oxygen in the water. If water that contained simply carbonic acid were introduced, an insoluble ferrous carbonate would be formed on the surface of the iron; but as it was assumed that there was a large amount of carbonic acid, in the present case, part of the ferrous carbonate would be immediately dissolved, and part might escape into the second filter. The Author had properly provided a dash-over arrangement by which the water was thoroughly mixed with the oxygen, and the result was that ferric oxide was formed, and the

Mr. Atkinson

Mr. Atkinson. carbonic acid was absorbed by the water: then the ferric oxide, being insoluble, was ready to be separated by the sand filter. Going a step further, the free carbonic acid was sufficient not only to dissolve the carbonate of lime in the water, but it was also in excess. When it entered there was the same process that had been already described but with this addition: that there was a precipitate of carbonate of lime, and that precipitate was in the body of the filter itself. Assuming that the velocity of the water was not such as to carry some of it forward into the second filter (he had been informed that some of it did go), the filter would become useless. It was now seen that in the filter there were three agents; ferrous oxide, ferric oxide, both of which were insoluble, and carbonate of iron, which was dissolved in the excess of carbonic acid. Then organic matter and living organisms were introduced; and what he desired to know was, whether the ferrous oxide abstracted oxygen, or whether the ferric oxide added oxygen to the organic matter, and thus broke it up, or whether the carbonate of iron acted in any way. It would be interesting to learn which of the three agents was the efficient one, because he thought the same effect might be obtained in a better and simpler way. If it was the ferric oxide and the ferrous carbonate, either or both, that operated, it would be desirable to mix a known quantity of ferrous carbonate in the water as it was pumped in. If the ferrous carbonate was that which acted upon the organic matter, it was present; and so with regard to ferric oxide; because in throwing it in it was immediately oxidised, and there would be a known quantity of ferric oxide mixed with the matter instead of the peculiar form of filter described where the iron was only 25 per cent. One would suppose that the water might escape without touching the iron at all. In referring to domestic filters Dr. Frankland had stated that they acted perfectly to the very end; but Mr. Atkinson had known three cases where they were abandoned. In one case the water that passed through was turbid and yellow, and in another, when the filter was opened it was so offensive that it could not be used again.

Mr. Burstal. Mr. E. K. Burstal said the Author had stated that the consumers had the choice of determining whether they would take water by meter or by assessment, and it would be interesting to know how the charges were arranged. It appeared to him that there must be, in some cases, great discrepancies. Taking the charge at 5 per cent. on the rental for domestic consumption, and 1s. per thousand gallons by measure, there would be some point at which those two scales crossed. In a house of £30 or £40 a year rental the

Mr. Burstal.

two charges might be nearly equal, but as the rent increased the charge would vary very much. In a house rented at £100 a year the owner would pay perhaps two-fifths as much only by meter as he would by assessment. There would be a very great disadvantage in introducing the meter-system for domestic purposes, not only on account of the great increase of capital, but from the fact that water was of course necessary for the poor and for the general well-being of the community. The Antwerp Waterworks were designed for a population of seventy thousand, and the number of meters would be, say, seven thousand, which would involve a capital outlay of about £28,000 and an annual charge of about £2,800 merely for the machines for measuring, He thought that was totally unnecessary if good fittings were introduced; in fact it would be prejudicial to the community, and restrict the use of water among the poorer classes. With regard to the thickness of the pipes, he thought 0·65 inch was thin for 20-inch pipes, and he was at a loss to know why that should be the thickness of some of the pipes while others were 0·75 inch thick. No doubt there was some reason for it. Strangely enough the 0·65-inch pipes were tested to no less than 850-feet head, while the others were only tested to 450-feet. The 0·65-inch pipes were cast in Germany, and he believed the feeling as expressed in the Paper was in favour of German pipes. He should be glad to know if they were turned out in as clean a condition, and with a coating as perfect, as was usually done by English firms. In England it was generally considered essential to be able to flush entirely every main in the town, and that each main should be controlled by its own special valve. If there were two or three or four valves to one district occasionally one would be left shut, and the system of circulation would be entirely stopped. Some two or three years ago he had five or six valves controlling one district, and he repeatedly found that one or two were left shut. It was only by disconnecting them all, and insisting upon one valve for each district that a proper supply of water was ensured. It was a pity to have two or three valves in one district, because in case of fire when a supply of water from two different quarters was relied on, owing to the carelessness of the turncock there might be a failure. With regard to the use of an engine of 170 HP. to keep up the supply at night, when it was small, it appeared at first sight that a very small engine would do the work, a larger engine, of course, being started in the event of a telegram being received from the town saying there was a fire, or any other contingency. The source of supply from which the water was taken was a tidal

Mr. Burstal. river, and the water was only admitted an hour and a half in the twenty-four hours, three-quarters of an hour each tide. There were four considerable towns on the river, the population of which was not less than 40,000, besides numerous villages, and the sewage from that population was continually coming down the river. Then there was Malines, containing 40,000 people, which sent up its sewage upon the flood, so that sewage came into the river from above and below Waelhem. It was evident from the specimens after treatment that spongy iron must have a very great effect upon the water. Glancing at London under similar circumstances, the population supplied by the water companies was about four millions, and the capital of the companies was about £12,000,000. The cost of spongy iron at Antwerp for seventy thousand persons was £8,000, and the cost in London would be probably £400,000, or if it was only used by the five companies drawing water from the Thames, £230,000, which would be about 3 per cent. on their existing capital. The Antwerp filters were being worked at the rate of about 6 gallons per square foot per hour; but as one of the filters would always be out of use, being cleaned, it might be said that the rate of filtration through the filters in full work was 9 gallons per square foot per hour. The London Waterworks Companies were only passing water through filters at the rate of 2 gallons per square foot per hour. Therefore if one-half of the filter-beds of the London companies could be fitted with spongy iron, assuming that it answered its purpose and was found to last, it would only be necessary to pass water through at the rate of 4 gallons per hour, which was not an excessive rate.

Mr. Robinson. Mr. Henry Robinson said it appeared that there was an entire absence of "previous sewage contamination" such as would exist from the remarks of the last speaker (Mr. Burstal). He desired to direct attention to a communication from Mr. G. Higgin, M. Inst. C.E., with reference to the water of the River Plate.[1] The water was described as containing a large amount of very finely-divided matter, which was incapable of being removed by ordinary filtration. Chemical treatment was suggested as a means of removing it, using sulphate of alumina, or some salt of iron. The means ultimately adopted for purifying the water was a filter about 2 feet 3 inches thick, containing a layer of about 3 inches of finely-powdered cinders, and it was interesting to know that the powder was essential to the efficiency of the filter. Without the

[1] Minutes of Proceedings Inst. C.E., vol. lvii., p. 272.

powdered portion it did not act so efficiently, but with it very good results were produced. The amount of water passed through the filter was considered to be less than 700 gallons per square yard per day. In Mr. Anderson's Paper it was stated that the water was estimated to pass at the rate of 140 gallons per square foot per day, which would be 1,260 gallons per square yard per day. Taking the usual calculation of water-supply from the water companies in London at 700 gallons per day per square yard, there appeared to be some discrepancy, unless there was some special means of passing the water through rapidly. Mr. Higgin stated that with his filter 4- or 5-inches head was sufficient to pass the water through. He did not know whether there was any special way in which the water percolated, but if not, the amount calculated was much in excess of what was found in practice in this country. He thought that those who were interested in the filtration of impure fluids could not do better than read a paper brought before the Society of Arts last year by Mr. Warington, on "Some Practical Aspects of recent Investigations on Nitrification." If it was true that spongy iron was able to destroy the germs of bacteria which reproduced themselves at such an enormous rate, and were so difficult to arrest that Mr. Folkard in his Paper last Session had stated that about a thousand would go abreast through any sand filter, all would be glad to use it where the water was derived from a source liable to a contamination of that kind. Mr. Robinson.

Mr. JABEZ HOGG said his remarks would be entirely confined to the hygienic or medical view of the subject. During the cholera visitation of 1858 he showed that the air, of towns in particular, contained a large quantity of living germs of various kinds, animal and vegetable, chiefly the latter. These germs or seeds were carried about by the wind, and ultimately deposited over vast tracts of land and water; or they were brought down by heavy rains, when they penetrated the soil and were productive of fungoid diseases amongst vegetable crops, as the potato blight, &c., or if deposited in lakes or rivers, they originated diseases amongst animals chiefly of the zymotic class. There was no way of preventing contamination of tidal flowing streams and rivers. This went on incessantly, day and night. A tidal river, as that of the Nethe at Antwerp, must suffer, as did most others, from various causes, as those engendered by traffic or navigation; the excreta of animals, and the manure distributed over the surrounding cultivated land. The latter, together with dead and decaying organic matter, would be carried into all rivers by rains. There was yet another Mr. Hogg.

Mr. Hogg. source of contamination, that due to the floating population, and probably to a still larger population living on the banks of rivers, and sending into them a considerable quantity of sewage and animal refuse. Owing to causes of this kind, and from the muddy nature of the banks between which the Nethe flowed, it was impossible by any system of sand filtration to separate the suspended material, mud, and filth, and convert the water into drinkable water. It was so bad, the Author of the Paper said, that it could not be made good enough to enter into successful competition with the then existing supply of Antwerp, drawn from dangerously-polluted shallow wells, into which adjoining cesspools were allowed to drain; but notwithstanding which, the water was bright and sparkling, and possessed of an agreeable flavour, so little reliance, apparently, could be placed upon the eye and palate for the determination of the purity of water. The Nethe water was so very impure that it was generally condemned as unfit for domestic uses of every kind. Fortunately, however, for Antwerp, a new material had been met with—spongy iron—and the waters of its muddy river were made bright and sparkling, "pure and wholesome," as seen by specimens on the table. Spongy iron was reduced hæmatite ore, melted at a low temperature by means of carbon; it was thus rendered vesicular, or spongy, and was easily broken up. It was suggested, that it was well nigh indestructible, for water passed through the Antwerp filters "has varied but little in brightness or in quality, and the beds of spongy iron and gravel seem to be nearly unaltered" after eighteen months of constant use; while "the quantity of suspended matter in the water renders it necessary to scrape off and wash the top layer of sand in the higher filters about once in every six to nine days."

In addition to its oxidizing[1] effects, it had the property of softening water, and, "since the boilers have been fed with filtered water little or no scale has formed;" and what was more surprising and interesting to all water-drinkers was, that spongy iron "is absolutely fatal to bacteria and their germs." After reading this panegyric of spongy-iron filtered water, one was naturally anxious to learn more about it; but no further explanation was offered by Mr. Anderson. No chemical analysis of the water

[1] It would be more correct to describe the effect as one of deoxidation, for water passed through, or left in contact with, spongy iron lost its oxygen, and in consequence acquired a vapid taste; it was for this reason, no doubt, that the Antwerp water, after filtration, was once more "exposed to the air, and finally passed through a sand filter."

before and after filtration was given, and it was consequently left to the imagination to supply by what agency softening was produced, and one-half of the carbonate of lime in the water removed, without choking up the filters; in short, how a turbid and very impure water, loaded with an unusually large proportion of highly nitrogenised organic matter, was constantly and by one process, transformed into a pure water, and all harmful matter removed from the water by an agency altogether beyond the ken of the chemist. Dr. Frankland had visited the works at Antwerp, and had reported that the results were "eminently satisfactory from a purely chemical point of view." But on turning to his recent work, "Water Analysis," it was stated, with regard to all river waters, that "although the improvement of excrementally-polluted water by filtration may reasonably be considered, on theoretical grounds, to afford some feeble protection against the propagation of epidemic diseases by water, no trustworthy evidence can be adduced in support of such a view." Mr. Hogg firmly believed in this statement, and although he knew of no reason why Dr. Frankland should not change his opinion, he was convinced that "trustworthy evidence" was still wanting, that spongy iron "is absolutely fatal to bacteria and their germs." It was evident, however, that this important point would not be cleared up and set at rest by any further appeal to chemical analysis, and this, probably, was the reason why the Author had omitted to give analyses of the water of the Nethe before and after filtration. The dogmatic assertions of certain chemists as to the purity and wholesomeness of this or that sample of water would not avail much, when the fact became more widely known that no analysis of water enabled chemists to gauge its quality, while it was almost certain to destroy every vestige of the minuter germs of organic life—the active agents in the production of specific forms of disease. Indeed, when infective matter had been purposely added to water, and a portion of it submitted to a skilful chemist for analysis, he utterly and entirely failed to discover it.[1] Water, then, might be bright and sparkling, and yet contain the germs of disease. Mr. Hogg.

[1] Professor Mallet, at the instance of the United States Board of Health, had lately, in conjunction with other chemists, carried out a series of test investigations to determine the value of chemical analyses of water, and he confessed that "it is not possible to decide as to the sanitary quality of a water by the mere use of a process for the estimation of organic matter or its constituents, and that there is no sound ground on which to establish such 'standards of purity' as have been proposed, fixing the exact amount of organic carbon or nitrogen, albuminoid ammonia, or oxygen of permanganate consumed, that shall be permissible."

Mr. Hogg. Where, then, or to whom, must the public look for light and truth in water examinations? Under the circumstances, and in so important a matter, it was necessary to see with an eye that was even more than microscopic, and to apply a test that was more than chemical, but which was hygienic, or medical and physiological. Pasteur, Chauveau, and Koch, had taken, and were still taking the latter course, with remarkable success. It was but necessary to dip a needle into the suspected fluid, which was usually bright and transparent to the eye, and insert the drop into the skin of an animal, and in a few days it would be dead, as formulated by physiologists. Dr. Koch had quite recently originated another method, which gave visible indications of organic vitality in any suspected or impure water. His process was a simple one, known as the gelatine process: "It was a method less dependent on the opinion of the chemist or operator; moreover, a photograph of the result could be taken and preserved as evidence." About 2½ per cent. of pure gelatine was heated and mixed with the water to be tested, and the mixture formed a transparent mass, which was not movable like water itself. "When soluble or unobserved matter developed from the organic matter of the water it made itself visible in a solid and insoluble form, it did not fall to the bottom; but each active point showed around it the sphere of its own activity. That sphere could be observed, for it remained long. The gelatine preserved and fixed the whole action, so far as the more striking results were concerned, and it kept a record for a time, both of the quality and intensity of life in the liquid." When a centre acted, it made around it a sphere in some waters, an ovoid in others, and the sphere, which had the appearance of a thin vesicle, was seen to contain a tiny drop of liquid. These spheres formed in a day or two, according to the quality and temperature of the water; in another day or two, a whitish deposit appeared in some of them; and this, if removed with a pipette, and submitted to microscopical examination, was found to be a putrescible fluid containing myriads of living bacteria freely moving in it. Dr. Angus Smith had tested Dr. Koch's gelatine process, and had thereby convinced himself of its great value, and the significance of the results obtained. Mr. Hogg submitted some tubes and photographs, as records of the examinations of Manchester and Stockport sand-filtered waters. Certainly, nothing could be more striking and convincing, for they at once appealed to the unaided vision of the skilled and the unskilled in these matters. His own experiments fully bore out those of Dr. Angus Smith, and he had

found that water passed through a spongy-iron filter, when submitted to the gelatine process, did not support the assertions made by the Author of the Paper, neither did it kill bacteria, nor arrest their development in a polluted water, or one favourable to their growth. Mr.Hogg's examinations had been chiefly confined to the water delivered to his house by the New River Company, this being one of the best of London waters; the Thames being the worst. In three days he had had ample proof of the presence of bacterial life, and he had removed them, and determined the species under the microscope. He was of Dr. Angus Smith's opinion, from what he had seen, that "chemists must be prepared for a new condition of things." With regard to the photographs which he was able, through Dr. Angus Smith's kindness, to show to the meeting, these were not intended to illustrate any special investigations; but rather those of an incidental character, made with the view of testing Dr. Koch's gelatine process. Of the action of spongy iron as a filtering material Dr. A. Smith at present wished to offer no opinion. His experiments so far would be found in the Proceedings of the Literary and Philosophical Society of Manchester. The results of Mr. Hogg's later experiments proved very conclusively the extraordinary tenacity of bacterial life. They resisted spongy iron as they did nitric acid and a number of other deleterious agents. Mr. Hogg.

Mr. Bischof desired to make some remarks on the purifying property of spongy iron. With regard to the chemical purification of water the results which had been published by him from time to time during the last ten years had been confirmed in the Sixth Report of the Rivers Pollution Commission, and also in several reports to the Registrar-General. He would only allude to one of those reports, made at a time when the water of the Thames was unusually impure, viz., on the 6th of January, 1877. At page 6 would be found an analysis of unfiltered and filtered Grand Junction water; the difference would be seen to be very remarkable. The organic impurity was reduced to about one-tenth, which was an unusually large reduction. The organic nitrogen was the same in the filtered Grand Junction and the Kent water. The organic carbon in the filtered Grand Junction water was 0·038, and in the Kent water 0·048. The only figure which was apparently against the filtered water as compared with Kent water was that of ammonia, which, as explained in the report, was due to the reduction of nitrates by metallic iron. This was a chemical reaction which any one could readily test for himself. On filtering a weak solution of saltpetre through spongy iron ammonia was formed; this Mr. Bischof.

Mr. Bischof. of course could not be looked upon with the same suspicion as the ammonia, which was the product of fermentation. In the Nineteenth Army Medical Report, page 170, would be found a record of a number of experiments on different filtering media, and the comparison there made between animal charcoal and spongy iron well brought out the merits of the latter. It was stated "*Animal Charcoal.*—When water, which has been filtered through charcoal, is stored for any time it soon begins to show evidence of low forms of life, and after a time a more or less abundant sediment of organisms becomes formed . . . . Occasionally it becomes distinctly offensive."—"*Inorganic Substances.*—Of these the most important at present before the public is the spongy iron. This is a very powerful filtering substance . . . . The action of spongy iron is slow but complete; about twenty-two minutes is the time of exposure, and this is usually sufficient to purify all but very impure waters. The water filtered shows no tendency to favour the growth of low forms of life, and may be stored with impunity." He would also call attention to the Statistical Sanitary Report of the Prussian Army from 1874 to 1878. On page 6 was recorded a series of experiments with a great many different filtering media, all of which were found inefficient, or even dangerous, through increased contamination of the water by the filtration. The report then continued: "More favourable were the results obtained with the spongy-iron filter constructed by Professor Bischof." Here follows a description of the spongy-iron filter, and the trials and analyses. The following conclusions are drawn:—"The improvement of water effected by this filter, both as regards the quantity and quality of various impurities occurring in water, which are important from a sanitary point of view, *is unquestionably greater than that by any other known system of filtration.* This has of late been further confirmed, amongst other instances, by the experience gathered in the military hospital at Emden." His results had further been confirmed by the chemists of Somerset House laboratory, who made a series of experiments on behalf of the Secretary for India. He might also mention that two years ago the Sanitary Institute sent round to all the makers of filters asking them to submit specimens for competition. The spongy-iron filters, and a number of others, were submitted, and the spongy-iron filter obtained the prize. Chemical examination was made, but he did not know whether there was any microscopical investigation. Several years ago he constructed, at the West Middlesex Company's works, a 3-feet spongy-iron filter, which proved a failure on account of certain engineering difficulties

Mr. Bischof.

which he had not then overcome; but with regard to the quality of the filtered water, he was informed that the company's chemist, in making an analysis by the albumenoid-ammonia process, found the albumenoid ammonia reduced to exactly one-tenth. It was admitted that the quality of the filtered water was unexceptionable. It might be asked why, if the process was a success to such an extent, it was not followed up. That was mainly owing to the course of legislation. Sir Richard Cross's bill assumed at the time a more definite shape, and the company did not like, being in such an uncertain condition, to enter upon any novel experiment; indeed, it was rather an awkward thing for companies to admit that their water required purification. It was perhaps unnecessary for him to enter into the defects of that experimental filter, but he might be permitted to say that in his opinion the difficulties connected with it had been overcome in the Antwerp filters. Dr. Frankland's analysis of the filtered and unfiltered water at Antwerp might also be regarded as confirming all his results. He had recently received a letter from Dr. Voelcker, which he desired to read. "I am very sorry that an engagement which I cannot break off will prevent my being present to-morrow night at the discussion at the Civil Engineers on Mr. Anderson's Paper, for I should have been glad to add my testimony to others who have found spongy iron an efficacious filtering medium for removing objectionable organic impurities from drinking waters, and affording the means of rendering waters of a doubtful character wholesome. I have now had one of your hand-filters in daily use for more than three years, and not found it necessary as yet to renew the spongy iron in my filter. All I found necessary to do was to break up periodically, say once in twelve months, the hard incrustation of carbonate of lime and oxide of iron, which in the course of that time is formed in the surface layers of the spongy iron, and which prevents the passage of the water with sufficient rapidity through the filter. This being done I find the spongy iron just as efficient now as it was when I first put up the spongy-iron filter." With regard to the comparison between the effects of spongy iron and sand, and of sand only, he would refer to the Paper under discussion, in which it was distinctly stated that suspended impurity, objectionable taste, colour, &c., could not be removed by ordinary filtration, but that they were removed by filtration through spongy iron and sand. It had been said that a filter acted in keeping back organic matter. In that case what would happen? The organic matter must, in the course of a few days, enter into a state of putrefaction,

Mr. Bischof. and the filter must become a focus of contamination instead of purification. Any filter, therefore, which only acted mechanically by keeping back organic matter would be worse than useless. With regard to ferrous carbonate it was slightly soluble, and that of course altered the whole state of things. He could not say what it was that acted in spongy iron. It was difficult to tell how a seed put into the soil germinated. It must, however, be accepted as a fact. It had rightly been said that it might be assumed either that the ferrous hydrate combined with oxygen forming a ferric hydrate, thus reducing the organic matter, or that the reverse might take place in the case of ferric hydrate which might be reduced, and the organic matter consequently oxidized or burnt. Both those re-actions took place. It might appear startling, but he would ask what took place in such a filter? There was a thick layer of filtering medium; the surface layer was prominently exposed to all oxidizing agencies, and therefore it would be much oxidized. Each grain of the spongy iron of the surface layer would be coated by a much thicker coating of oxide than down at the bottom. It was not, therefore, difficult to understand that the thick coating of ferric oxide at the top might exert an oxidizing action, whilst there might be at the bottom spongy iron not coated at all with oxide. In order to test the matter, he had taken a glass vessel with a neck at the bottom. Allowing water containing ferrous hydrate, or carbonate in solution, to circulate round rapidly, by degrees a film of ferric hydrate was formed on the inner surface of the glass vessel. He had observed that when he put hay infusion into the vessel, after some time the colour of the ferric hydrate became distinctly darker. What had taken place? He had no doubt that the ferric hydrate was reduced to the hydrated magnetic oxide. He emptied the hay solution and put in water, when after a time the colour of the ferric hydrate was recovered. That was an important point leading to the inference that the processes of oxidation and reduction might take place alternately without to any great extent, if at all, exhausting the purifying power of the material. It was scarcely necessary to say anything of the purifying power of ferric hydrate. Laundresses well knew that rust-stains were destructive even of the highly indestructible fibre of linen, cotton, &c. It should further be borne in mind that all the compounds that had a destroying action were present in the spongy-iron filter in the nascent state, and it was a chemical law that all bodies were especially active in that state, which perhaps gave additional power to spongy iron in destroying organic matter. Mr. Atkinson proposed, if he found that one of

the compounds was active, that compound should be used in a state of purity for purifying water. But chemists could not deal with ferrous compounds; they were by far too rapidly oxidized, and they could only be obtained if formed in the filter itself during filtration. Mr. Atkinson wanted to know how calcic carbonate was abstracted by spongy iron. Ferrous hydrate was formed in the first instance. This had a very great affinity to carbonic acid. Was it, therefore, difficult to understand that ferrous hydrate should combine with so much of the carbonic acid that there did not remain sufficient to keep the mono-carbonate of lime in solution? That appeared to be an explanation that would commend itself to every chemist. On one occasion he had carried the water for some distance in an open conduit on to the second filter, and when it came in contact with the oxygen of the air, the oxidation of the soluble ferrous compounds took place to a certain extent, being deposited in the conduit as ferric hydrate. On mixing the latter with water, to which he would add some hydrochloric acid, it would be seen by the effervescence that by far the largest proportion of carbonate of lime separated on the top of the second filter, whence it was from time to time scraped off with the ferric hydrate. Of course some of it was deposited within the body of the spongy iron, but it had been a principle of his to render the body of the filtering medium, which was to exert a chemical action, as porous as possible. Therefore ample provision was made for any such deposit. It had been stated by a previous speaker that it would be difficult to find a town having a water-supply from such an impure source as Wakefield. In the Sixth Report of the Rivers Pollution Commissioners were two analyses of unfiltered water from the Calder, one made in 1868 and the other in 1869, both agreeing very closely. He would not give the figures, but it would be sufficient to state that, in the case of the Antwerp water, the organic carbon was 50 per cent. more than in the water at Wakefield, whilst the much more dangerous organic nitrogen was 400 per cent. more. The difficulty, therefore, of dealing with the water at Antwerp should not be under-rated. With reference to the use of domestic filters, it would be sufficient to say that, if thousands of persons could manage them easily to their own satisfaction, the two or three who might not be able to do so should look to themselves for the cause of their inability. With regard to the subject of physiological purification, he had read two Papers before the Royal Society, and one before the Society of Medical Officers of Health. In the experiments which he had detailed he Mr. Bischof.

Mr. Bischof. had used spongy iron pure and simple, unmixed with gravel, and it was therefore incumbent on him to repeat the experiments on the Antwerp mixture. He had done so, and the results were given in the Paper read before the Society of Medical Officers of Health. His results had been confirmed in the Nineteenth Army Medical Report, pp. 170, 171, already referred to. It was there stated that, whilst water which had been filtered through animal charcoal did not keep, and soon showed signs of the formation of low forms of life, that passed through spongy iron was found not to show any such signs, and did keep. He might also mention that Professor Heyman, of Stockholm, had made a series of experiments, repeating and confirming his experiments, and they were recorded in the Swedish journal "Hygeia," 1881. Dr. J. Lane Notter had also published a number of experiments with similar results. Dr. Notter stated in "The Sanitary Record" of the 15th of November, 1880, p. 164: "Samples of water were placed in glass-stoppered bottles, and in bottles without stoppers. After a considerable number of weeks had elapsed, they were carefully examined under the microscope with a one-eighth and one-twelfth immersion lens. The original water contained very little sediment, only a little mineral grit and ferruginous matter. After passing through the filter it showed no sediment whatsoever, neither were any forms developed in it; the samples remained clear and free from sediment for months. All our experiments proved conclusively that spongy iron yielded nothing to water to favour the growth of lower organisms." Dr. Notter had made the latter remark with reference to animal charcoal, which he found did favour the growth of those organisms. Mr. Bischof had succeeded in keeping various organic matters, such as butter and oleomargarine, under wet spongy iron for years. With reference to that subject Dr. Voelcker said, in his letter referred to before:—"I should also have been glad to say a few words with respect to the remarkable antiseptic properties of spongy iron. You will recollect that I kept in my house, under my own observation for several months, fresh, unsalted butter, covered with spongy iron and water. The butter, unfortunately, was not well made, the buttermilk not having been properly removed from it; nevertheless the unsalted butter, after the lapse of several months, was far better than I anticipated, and I am satisfied that the result could not have been obtained unless the wet spongy iron possessed strong antiseptic properties." Some gentlemen had referred to an experiment and exhibited photographs which, they thought, showed that spongy iron was not, or at least not completely, destructive of bacterial life. They found

that by the gelatine test, water filtered through spongy iron exhibited a few "spheres" containing active bacteria. Without expressing an opinion on the prospective value of that test, he had to point out that no conclusion as to the completeness of the destruction of bacteria by spongy iron could be drawn from the experiment, because a very material point had been entirely missed. He had in all his Papers laid great stress on the absolute necessity of not exposing the water to be used for such experiments, after filtration, to the infective influence of the atmosphere. This had been overlooked. The air was full of bacteria, and instantaneous contact with the atmosphere was quite sufficient to produce results such as those shown in the photograph. But if the test would turn out as valuable as Dr. Smith anticipated, the specimens filtered through spongy iron and that of unfiltered water, which were photographed side by side, gave a complete confirmation of the purifying power of spongy iron. The sample filtered through the latter only showed very few isolated "centres," whilst the other appeared as if dotted all over with small-pox. How far might any conclusion be drawn from such destruction of bacteria as had been described, upon the destruction of specific zymotic poisons? Some entertained the view expressed by Professor Huxley, at a meeting of the Chemical Society, that, as such epidemic diseases as splenic fever, pig typhoid, and the cholera of fowls, were invariably caused by bodies of the nature of bacteria, so there was every reason to believe that analogous diseases in man were caused by similar organisms. He had lately had a discussion on the subject with Dr. Schaefer, of University College, who said he thought it likely that spongy iron would have the same action upon zymotic poison as upon bacteria. The absence of putrefaction in the water would be, in his opinion, a very considerable guarantee, because there was a great deal of evidence to show that the specific poisons were much more virulent if surrounded by putrid matter than otherwise. Again, the absence of food by the reduction of organic matter in water was a most important factor. It had been stated by Dr. Cohn, of Breslau, that one single bacterium would be sufficient to convert the whole ocean into a solid mass by its progeny in less than five days, supposing only a sufficiency of food. It was known from epidemics spread by contaminated milk, how their virulence was enhanced, if food was plentiful. But the crucial test was practical experience. He had before him a number of official reports on the subject. One report was from Fort George, in which it was stated that zymotic diseases threatened to become epidemic on Mr. Bischof.

Mr. Bischof. account of the bad quality of the water. In the next report it was stated that all complaints had ceased, spongy-iron filters had been introduced and remedied everything. At Shoeburyness the garrison had been surrounded by epidemic typhoid, but not a single case occurred in the garrison, which was supplied by spongy-iron filters. In both instances the sanitary improvement had lasted now for three years. At Emden, in Hanover, there had been two epidemics, and the water was considered to be at fault; spongy-iron filters had been introduced, and there was no more epidemic. At Coblentz also there had been an epidemic of typhoid in one of the fortresses. The spongy-iron filter was introduced, and no further case occurred during its use. There was there a great mechanical difficulty in filtering the water, which was more like milk in appearance, being full of minute particles of clay, which choked the filter. On that account the authorities determined to deepen their well by about 100 feet. Then they thought they were safe. Another epidemic broke out after the filtration was discontinued and the water taken from the deep well. It only remained that he should thank the members for their kindness in discussing a matter which, at least in its origin, was his own work. He was especially thankful to those who had raised objections, because he quite agreed that scepticism was the root of all science—a root which sent life into all the branches, and without which there could be no real progress.

Mr. Folkard. Mr. C. W. Folkard observed that the admixture of gravel with the spongy iron in the Antwerp filters had been discussed by two or three of the speakers, who seemed to be of opinion that the purification of the water would not be complete under such circumstances; but this seemed to him to be erroneous. One word, however, about the process itself. About twenty-five years ago Dr. Medlock, in conjunction with Mr. Joseph Quick, M. Inst. C.E., made a number of experiments on the purification of Thames water by metallic iron. The water of the river at Battersea was left in contact with iron wire and plates in a large tank for twenty-four hours, and the improvement in quality was very marked. The process was tried on the experimental scale, with the water supplied to Amsterdam, the quality of which was unsatisfactory, and the result of the treatment was a very great improvement. Whether the process was adopted at Amsterdam or not he did not know, but it was interesting as being doubtless the forerunner of the one under discussion. As to the composition of the Antwerp filtering material, at first sight the admixture of an

Mr. Folkard.

inert substance with spongy iron seemed calculated to impair the efficiency of the filter, by allowing part of the water to pass between the gravel without being subjected to the purifying action of the iron. It was plain that the Author relied on purification by the passage of the water over the spongy iron, and not entirely, or even chiefly, through its pores, it being evident that the water would take the easiest course presented to it, viz., between the lumps of gravel and spongy iron, and not through the minute passages in the latter. Under these circumstances there was apparently a chance of bacteria and their germs passing through the filter without contact with the iron at all, and therefore uninjured. Fortunately, there was a parallel case in gas-purification, and the results obtained had, in his opinion, an important bearing on the subject. In purifying the crude gas from sulphuretted hydrogen, oxide of iron was used, mixed with three or four times its bulk of foreign matters, chiefly sawdust and sulphur. Here, again, it might be imagined that some of the gas would pass between the sawdust and the oxide of iron, and so escape purification; but this was not the case, perfect removal of the sulphuretted hydrogen by the mixture being quite easy. It seemed, therefore, fair to conclude that complete destruction of bacteria and their germs was possible with the mixed gravel and spongy iron, provided the thickness of the layer of filtering material was properly proportioned to the rate of flow through the filter, the area of the filter being such as to permit the required quantity to pass through that thickness. The real disadvantage of mixing spongy iron with a foreign substance was seen when the iron became unfit for work by deposition of carbonate of lime in its pores and on its surface, or by vegetable and animal growths. In this case the Antwerp filters would allow the water to pass as freely (or nearly so) as at first; for although the action of the iron would be suspended, the water would find its way between the gravel, and a return to the old method of sand filtration, pure and simple, would take place. In this respect the Antwerp filters were inferior to the Bischof domestic filters, which, as stated by Dr. Frankland, purified the water completely as long as it could pass—a property which makes them absolutely safe. This, however, not being the case at Antwerp, frequent examination of the water would seem to be necessary to ascertain that the spongy iron was acting efficiently. For this purpose a simple microscopic examination of the water would probably be sufficient without invoking the aid of the present processes for determining organic matter in potable water. The

Mr. Folkard. iron dissolved by the carbonic acid in the water was again rendered insoluble by exposure to the air, and was removed by the second sand filter in the form of red oxide, and there could be but little doubt that the act of precipitation of such a gelatinous substance as hydrated oxide of iron tended to make the water clear and bright, by inclosing and carrying down minute suspended particles, including bacteria. This, therefore, was an additional safeguard against them. A microscopic examination of the oxide of iron deposited would show if this was the case. Lastly, with reference to the cost of the process. Even at the present high price of spongy iron, the outlay was slightly under 3 per cent. of the total cost of the works, and assuming that the material required renewal every two years, the amount was not extravagant, provided the water was thoroughly purified and deprived of all noxious constituents. In addition to this, however, it must be remembered that spongy iron was simply the unmelted metal, and if made by the 100,000 tons, would probably cost very little more than hæmatite pig, while the spent material (allowing for loss of weight by partial solution) would probably return at least 50 per cent. of the original cost.

Mr. Anderson. Mr. ANDERSON, in reply, said that the tone of some of the speakers appeared to indicate an opinion that the filters were made for the purpose of employing spongy iron, and not because the spongy iron was necessary for the works. It had been suggested, indeed, that spongy iron was a very good filtering medium, but that sand was quite as good; and a calculation had been put forward of the cost of spongy iron, as if it were some kind of ornament, or article of luxury, instead of being, as it really was, a necessity. He thought, therefore, that he must recount the reasons why spongy iron had been adopted. The authorities at Antwerp were greatly in want of water for municipal purposes—watering the streets, flushing the sewers, extinguishing fires, and the like—and they would have been content with the waters of the Nethe filtered through sand, if they could only have got them; but it was evident that the supply of a coloured turbid fluid would not have been a profitable undertaking to a water company in a town where most of the houses were supplied from wells, the water in which though contaminated at any rate looked very well. His firm consequently requested Mr. Ogston, who had more than once acted for them in similar circumstances with success, to find out what medium of filtration there was which was practicable, and which would make the water a more marketable commodity. He accordingly tried

first to filter the water of the river, samples of which were sent Mr. Anderson. him, through sand. But filtering through sand, even at a rate which was below anything commercially practicable, entirely failed to remove the colour and the muddiness. He then tried, more by way of a crucial test than anything else, because it was not a kind of filter commercially possible, twenty layers of compressed Swedish filter-paper, but that failed to remove the colour to any marked extent. Animal charcoal was out of the question on account of its cost, £18 per ton, and the expense of revivifying. Spencer's magnetic-oxide of iron was naturally turned to because it had been used with great success at the Stowmarket paper-mills for separating the iron dissolved in the waters of the artesian well. There were, however, difficulties in the way of obtaining Spencer's carbide, which was moreover expensive and uncertain in quality. The only remaining substance, with the properties of which Mr. Ogston had been for some time acquainted, was spongy iron, and the experiments made with it enabled him to recommend the adoption of it. The three principal points to be attained appeared to have been lost sight of. The discussion had centered mainly on the question as to whether bacteria and their germs were, or were not, destroyed by spongy iron; but what was wanted was a substance which would take out the colour of the water, which would remove the turbidity, and which would reduce the organic contamination to an amount which chemists would admit to be reasonable; and he thought he might safely challenge the bringing forward another substance which, at the same cost and with the same efficiency, would produce the three effects he had named. There was also an additional property possessed by spongy iron which they did not think of at the time, and which he believed that further investigation would prove that it did possess, that of destroying bacteria and their germs. That was an additional advantage in favour of spongy iron.

Another question that had been raised was the mode adopted to preserve the filters from frost. In the first place he should point out that the aeration of water between the spongy-iron filter and the sand filter was an essential feature of the process. It would not do, therefore, to let the cascade in which the water fell from the spongy-iron filter into the sand filter, or that filter itself, get covered with ice. It was consequently necessary to adopt some such method as he had described. It had been suggested that a surface-condenser should be introduced and the waste heat of the engine utilized for warming the water. Of

Mr. Anderson. course that idea had been acted upon, but without the use of a surface-condenser which was not, in this case, necessary. The water from the hot wells was returned to the sump from which the screw-pumps derived their supply, and was lifted with the cold water into the filter-beds. After allowing for the heat converted into work, it could be easily shown that it would be impossible to raise the temperature of the water more than about $1\frac{3}{4}$° Fahrenheit by this process. That amount of warming was sufficient for ordinary weather, but it was foreseen that if continuous colder weather appeared, and last winter's experience justified the foresight, something more would be needed. One ton of coal consumed per twenty-four hours was just sufficient to raise the water pumped 1° Fahrenheit when the engines were working full power, and he estimated that about 2°, in addition to the $1\frac{3}{4}$° due to waste heat, would be sufficient for any weather. Two tons of coal at 12*s.* 6*d.* per ton, which was the price at Waelhem, just represented the wages of five men employed night and day. Mr. Burstal appeared to hold the opinion that by proceeding south, the warmer the climate must necessarily become; and because upon the moors of Yorkshire he did not find it necessary to adopt means for keeping the filters clear of ice, he argued that it was not necessary to do so at Antwerp, which was further south than Yorkshire. But that rule did not apply; in fact, in the year 1879, when the works were commenced, the winter was an exceptionally hard one; there were forty nights of continuous frost, averaging 13° Fahrenheit below freezing-point, and on several occasions the temperature fell below zero. On twenty-two days the thermometer never rose higher than 11° below freezing-point, and the remaining eighteen days the temperature hardly rose above freezing-point. During that time, in the neighbouring town of Amsterdam, where he was sure the filters were used actively enough, sixty men were employed night and day to keep the surface of the filters free from ice. He thought that in this, as in most other matters, work which could be done by steam was much more efficaciously and economically performed by that agent than by hand. He now came to the question as to Dr. Koch's method of ascertaining the presence of living organisms in infusions or water by means of the gelatine test. He was glad to have that opportunity of alluding to a subject to which he had given some attention. It so happened that when Professor Tyndall's work "Essays on the Floating-Matter of the Air in relation to Putrefaction and Infection" came out, he was so much interested that he pursued the subject

further, and read Pasteur's works on kindred investigations, the Mr. Anderson. propagation of germs, the cause of fermentation and such-like action; and one of the things which impressed his mind was the difficulty of the experiments conducted with reference to such matters—the care, the patience, and the foresight necessary to do anything at all trustworthy. An idea might be formed of the difficulties surrounding such investigations when he remarked that the promulgation of the theory of spontaneous generation was not only possible, but obtained supporters among eminent men in this country and abroad, and that it required such rigid investigators as Pasteur, Dr. Burdon-Sanderson, and Professor Tyndall to upset it. The advocates of spontaneous generation brought forward evidence of this kind, "Take an infusion of beef, or fish, or of melon, or any substance of that kind, boil it for five minutes, and then bring it into contact with air which has passed through cotton-wool loosely packed into a tube, then through caustic alkali, and finally through sulphuric acid, and animal life will show itself in the infusion;" and they asked if it were possible that any living germs could exist after five minutes' boiling, and after the air had been purified in the manner he had explained. Professor Tyndall took up the question, and showed by the most conclusive proofs that it might take from four to six hours' boiling to kill the germs that might find their way into infusions of that kind, and that sulphuric acid and caustic alkali and loosely-packed wool were not competent to stop the passage of the germs unhurt into the vessels. Professor Tyndall, in the work already alluded to, mentioned that in his laboratory, where he had frequently made experiments to disprove the possibility of spontaneous generation in infusions competent to maintain animal life, those experiments had at first succeeded perfectly. He had been able to sterilize infusions by five minutes' boiling with the utmost certainty, keeping them for months unchanged in boxes in which impurities had been removed from the air; but suddenly the experiments failed and he could do this no longer. Suspecting the cause, he repeated his experiments in the laboratory at Kew, and there they again succeeded perfectly. The fact was that at Albemarle Street he had been operating upon some infusions made of old hay, and the germs from that old hay were so persistent that they resisted the ordinary methods of sterilization. He placed a temporary shed on the roof of his laboratory in Albemarle Street, and there the experiments were again repeated successfully; but with this precaution, that the operator was not to pass through the laboratory which was infected,

Mr. Anderson. because it was found that, if he did, he infected the laboratory above; he went by another way, and had to cover the clothes he used in the old laboratory with overalls, so that the contagion in them might not reach the vessels he was operating upon above. Some of the tubes which Dr. Tyndall had sterilized at Kew were exhibited at the Royal Society, and the contents of one of them went bad, becoming turbid and showing signs of life, while the others, treated in the same way, remained intact. He believed it was Professor Huxley who discovered that in the tube in which the contents putrefied there was a speck in the glass, through which the deleterious germ got in. He had gone into the matter thus minutely, although it did not appear to bear much upon the question, to show that unless Dr. Angus Smith and Mr. Hogg had conducted their experiments with the safeguards that were absolutely necessary, they were worth nothing. The experiments of the former gentleman, in Manchester, had been brought forward with a view of showing that the theory as to the effect of spongy iron upon germs could not be sustained. He confessed that he was very much astonished at what he found in the Paper. Dr. Angus Smith had recorded experiments with twelve specimens of water. The first was with distilled water; the second with Manchester water as supplied to the consumer; the third with Manchester water passed through spongy iron; the remaining specimens were waters of various kinds not filtered through spongy iron, and therefore did not bear on the question for the moment. The specimen of distilled water showed, after two or three days, signs of animal life, by Koch's gelatine process, which gradually developed into living bacteria. The water, as supplied to the consumer, showed the same result in a much more aggravated manner. As to the third specimen, Manchester water filtered through spongy iron, he quite expected to find it, as it had been brought forward in evidence that Dr. Frankland's theory was not tenable, the same as the water supplied to the consumers, but Dr. Angus Smith dismissed it with a single line: "Behaved exactly like distilled water." That was very satisfactory, and it corroborated so far the opinion that spongy iron had a strong effect upon bacterial life. It also showed that if distilled water could be affected in that way, and permitted living bacteria to be formed in it, there must be some flaw in the experiments, and those who had studied the subject would easily understand that, either in consequence of impurities adhering to the sides of the vessels, or from the dust deposited by the air, or from some impurity in the gelatine, the bacteria would appear. They were not in the water, but were imported into it,

directly or indirectly, from the air. No doubt the Manchester water, as supplied to the consumer, had a good stock of germs of bacteria to begin with, but the distilled water, and the water filtered through spongy iron behaving exactly in the same way, were probably originally in the same pure condition, and afterwards became contaminated in the manner Dr. Tyndall had so conclusively shown. Mr. Hogg had brought a large number of specimens of the water treated with gelatine, and there was in them an enormous development of life of some kind or other, but he thought it extremely improbable that the precaution had been taken that Dr. Koch would, no doubt, have taken if he had performed the experiments. He gathered that the experiments were made in the ordinary laboratory air, and if that were so, all the experiments to which he had referred showed that the animal life was not necessarily due to the water, but rather to the atmosphere and other causes. Professor Koch, as an experimenter, had a European reputation, and had he conducted the tests under consideration, he no doubt would have used all the safeguards which Professor Tyndall and Mr. Pasteur had found necessary. When, however, the experiments were conducted by other hands, and these precautions neglected, those who attempted to found theories or disprove theories by means of them would discover that they had been leaning upon a broken reed. Chemists were feeling more and more that they were incompetent to say, by their art, whether water was fit for dietetic purposes or not. The circumstance that it contained a certain amount of organic matter they admitted was no evidence of insalubrity; the only evidence it afforded was that the water impregnated with organic matter might possibly contain the germs of diseases which were associated with it. If, therefore, it were possible to find a substance, filtration through which would absolutely destroy germs or their progeny, he thought that the engineer would have at his command a new power which would enable him to construct works deriving their supply from rivers or other sources as impure as the Nethe, and to give, as had been done in Antwerp for the last eighteen months, an abundant supply of pure and palatable water. Mr. Anderson.

Mr. Jabez Hogg said, in explanation, that the experiments to which Mr. Anderson referred had been conducted with the greatest care, and during the past week had been repeated, with even more striking results. Dr. Angus Smith wished it to be known that when speaking of water passed through spongy iron in its relation to the gelatinous process of Koch, he said, it acted like distilled water, meaning the distilled water that he had used, Mr. Hogg.

Mr. Hogg. but which, on subsequent examination, proved to be inferior. Carefully distilled perfectly pure water, submitted to the gelatine process, showed no sign whatever of any change after many days.

Correspondence.

Mr. Booth. Mr. T. Booth remarked that about a year ago spongy iron had been substituted for animal and vegetable charcoal as a filtering medium at the Stamford Waterworks with beneficial results. It had proved efficient as a purifier, reasonable in price, and was readily cleansed from collected impurities. These were got rid of thoroughly by two valves, an inlet-valve and a discharge-valve below the filter-bed. To cleanse a filter-bed it was only necessary to admit sufficient water and close the valve, and then open the discharge-valve, and the water, passing rapidly through the bed in the reverse way to its ordinary flow, carried off all impurities into a neighbouring ditch. As the filters were duplicate this cleansing process could be effected when desired at the cost of a little trouble. The spongy iron was kept separate from the sand and gravel by being placed between layers of perforated bricks laid dry. The depth of spongy iron was 6 inches, and the water got filtered through gravel and sand twice (upwards and downwards). In July 1882, at which time the layer of spongy iron was only 5 inches thick, an analysis of the water yielded the following results. No. I. was water filtered through spongy iron, gravel and sand; No. II. was the same water unfiltered:—

	No. I.	No. II.
Total solids per 1,000,000, or milligrams per litre .	76·0	119·0
„ chlorine as chlorides	5·2	5·5
„ nitrogen as nitrates	7·3	9·1
„ free ammonia	0·01	0·03
„ albumenoid ammonia	0·04	0·10

He thought a great saving of labour might be effected if in the Antwerp Waterworks unfiltered water were admitted below the filter-beds, and a discharge valve fixed in the floor. The filtering operation would be quite as effectual upwards as downwards, and by the former method the heavier particles would be deposited on the floor ready to be blown out at the discharge-valve. This was better than scraping off the top layer of sand, which made the bed uneven, and it was well known that in that case the water would force its way through the weakest place only. Such substances as charcoal must be removed at frequent intervals, but

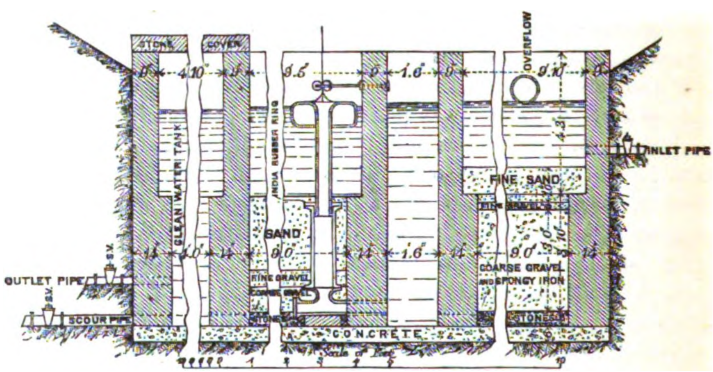
not spongy iron; and therefore the method of cleansing a filter as he had described was of the greatest value when the latter was used. Mr. Booth.

Mr. ALEXANDER McCULLOCH remarked that in the summer of 1881 he advised upon a supply of water for the mansion-house of Grange of Monifieth, near Dundee, as well as for the contiguous farm-steadings, cottages, offices, and conservatories. Water existed at a sufficient elevation for a supply by gravitation from two field-drains fed by land-springs at the daily rate of upwards of 10,000 gallons in dry weather. The water was of good quality, except that it contained a small portion of "oxidized nitrogenous matter present as acids of nitrogen." The proprietor, desirous of avoiding all risk, wished the water filtered in the most efficient manner. Mr. McCulloch had previously been aware of the experiments of Mr. Bischof and Dr. Frankland, demonstrating the value of spongy iron for destroying organic impurity, and he resolved to make use of it as a filtering medium. Mr. McCulloch.

The lower drain, yielding about four-fifths of the supply, at the point where the water was intercepted, was at an elevation above the bottom of the cistern supplying the high-pressure boiler and lavatories of the house of about 3 feet only, while the distance between these two points was a little over $\frac{3}{4}$ mile, and the size of the bore of the supply-pipe was 3 inches. It was therefore necessary to arrange the filters so as to give the least possible loss of head. A small tank was constructed on the line of the larger drain, with the sill of concrete and the walls of brickwork covered with a movable cast-iron plate. This tank was provided with an outlet pipe of 4 inches bore leading to the filter, a scour pipe of 3 inches bore, and an overflow pipe of 9 inches bore, the latter at a height of 16 inches above the sill of the drain. The filtering arrangements consisted of a tank having a concrete bottom, and walls of brickwork, 29 feet 4 inches long from east to west (the flow of water being from west to east) by 14 feet 4 inches wide from north to south, with a uniform depth of 8 feet 1 inch, with three cross-walls dividing the interior into four compartments, two filters, a small space between them, and a clean-water tank (Fig. 3). The bottom was of Portland-cement concrete 6 inches thick, the outer and division walls were of brickwork in Portland cement mortar 14 inches thick for a height of 3 feet 10 inches from the bottom, reduced to 9 inches thick above, the outer walls being vertical on the outside, the intake on the inside. The width inside from north to south was 12 feet from the bottom to a height of 3 feet 10 inches, and above that 12 feet 10 inches. The length inside of each of the two

Mr. McCulloch. filtering divisions of the tank from east to west was 9 feet for a height of 3 feet 10 inches, above that 9 feet 10 inches in the case of the spongy-iron filter, and 9 feet 5 inches in the other. The space between the division walls of the two filters was 1 foot 6 inches, and these were tied together by two longitudinal walls left open at the bottom. The inside length of the clean-water division of the tank was 4 feet from the bottom upwards to a height of 3 feet 10 inches, and above that 4 feet 10 inches. The walls of this compartment from the top downwards to the extent of 4 feet 3 inches were lined with enamelled fire-clay bricks, and it was covered with stone flags to 6 inches thick, having an opening for a manway, provided with a movable cast-iron plate, while galvanised-iron

Fig. 3.



Grange of Monifieth Water Supply.

step-irons are built into the walls for access to the bottom. The whole was slightly below the level of the ground, which, however, was excavated so as to leave the top of the walls 6 inches above the outer surface adjoining. A space 50 feet by 30 feet, containing the filtering tank and a small plot round, was enclosed with stone walls in lime mortar.

The western division of the tank was thus filled: on the bottom was a layer of stones broken to pass through a 3-inch ring 4½ inches deep, then 3 feet of spongy iron and coarse gravel in the proportion of 1 part of iron by measure to 4 parts of gravel, then a layer 3 inches thick of fine gravel, and finally a layer of fine sand 1 foot thick. The eastern division was filled thus: on the bottom was a layer of stones broken to pass through a 3-inch ring 4½ inches

deep, then a layer of coarse gravel 9 inches thick, next a layer of fine gravel 6 inches thick, and finally 2 feet of fine sand. The stones, gravel, and sand were all washed clean. Mr. McCulloch.

The water was delivered into the spongy-iron division of the filter by the 4-inch cast-iron pipe, through a fine screen of copper-wire cloth at the end of the inlet pipe. This screen protected the sand from scour, and retained a portion of the sediment in the water. The water was drained off from the bottom of the filter by fire-clay pipes of 3 inches bore laid with open joints, and was discharged into the division between the two filters. From this division it was conveyed by a 4-inch cast-iron pipe through the brick wall, and up through a stand-pipe on to the sand filter. The stand-pipe consisted of two parts. The lower portion was a cast-iron cylinder $7\frac{1}{2}$ inches inside diameter, lined with brass. The upper portion was a copper tube or piston $6\frac{5}{8}$ inches in external diameter, on which was placed a round india-rubber ring to fill up the space between the external diameter of the piston and the internal diameter of the cylinder. As the tube or piston was moved up or down in the cylinder this ring rolled round and allowed the tube to move easily and yet maintain a tight joint. The tube was provided with a copper float at the top, with a guide spindle moving between rollers. The water as it rose flowed over the upper surface of the copper float in a thin film, exposing a large surface to the action of the air to facilitate the oxidation of the iron taken up by the water in passing through the spongy iron. The water was drained off from this filter in the same manner as from the other, and was discharged into the clean-water tank, and thence through the outlet-pipe to the various points of distribution. The division between the two filters, and the clean-water compartment of the tank, were each furnished with scour-pipes having sluice-valves. The inlet and outlet pipes of the filtering-tank were connected by a by-pass with sluice-valves to provide for the water being used unfiltered when desired.

The water from the higher source, in addition to its superior elevation, was also of slightly better quality than that from the other. Provision was therefore made for the whole of the supply from the former being used by a reflux-valve placed on the inlet-pipe to the filter, between the point where the pipe from the higher source joined the inlet-pipe and the tank on the lower drain, and the overflow in the filter was a few inches higher than the overflow in the intercepting tank. When the supply from the higher source was insufficient, it was supplemented from the lower source.

Mr. McCulloch. The water was let on to the filters on the 20th of April, 1882, and, after an interval of about six weeks, the surface of the sand was scraped. By that time, the weather being hot, a green scum had formed in both divisions of the filters on the surface of the water; which, when an attempt was made to skim it off, was found to extend down to, and appeared to be growing out of, the sand. By the removal of a layer of sand of about ½ inch in thickness, the whole of the objectionable substance was got rid of. There were trees in the neighbourhood, and the seeds and leaves from these were blown into the water. Then, on account of the novelty of the arrangement in the district, the place was frequently visited by persons who climbed over the enclosing walls. To obviate these drawbacks the filters were roofed over, care being taken to leave proper space for ventilation. Since then the man in charge had visited the filters every week to open the scour in the intercepting tank and examine the filters. Once in two months he had lowered the water in the filters by stopping the supply and opening the scour in both divisions, partially only, not to let the water fall too rapidly, and had scraped off about ½ inch in depth from the upper surface of sand, and loosened the sand for some distance down. The spongy iron had not been interfered with since the filter was completed. The water as delivered was remarkably bright and palatable. From this experience Mr. McCulloch foresaw no difficulty in using spongy iron as a filtering medium on a large scale; and he agreed with the Author that there would be very little extra cost in carrying out this system compared to the ordinary system of filtration through sand. The daily consumption at present seldom amounted to 2,000 gallons, but it was expected that this might probably be increased to 8,000 gallons. The area of each filter at the surface of the filtering material was 108 square feet, and 8,000 gallons per day would give a rate of filtration of about 74 gallons per square foot. The cistern at the Grange of Monifieth was supplied at the bottom through a self-acting float-valve, the inner end of the inlet-pipe being provided with a back-flap to prevent the water returning when water was being drawn off the main at lower elevations.

Mr. Ogston. Mr. G. H. Ogston observed that, when first consulted by the Author of the Paper as to the best mode of filtration to be applied to the Nethe water, which was greatly in need of the very best system that could be found, he made a variety of experiments on the efficacy of sand filtration, under different circumstances, to see if it were possible so far to remove the suspended matter, and the colour, as to make the water presentable. In the town of Antwerp,

bad as the water actually was, its freedom in some districts from colour was undeniable. All attempts failed in the end. Experiments were tried with a great depth of filtering material, with very fine sand, and with very slow filtration; but the colour always was maintained, and only a portion of the suspended matter was removed. In order to prove that no modification of a merely mechanical filter would be effective, he passed the water under 6 feet of head through twenty folds of filtering paper pressed together. The pad was 2 inches in diameter, and but 3 ounces of water passed through in twenty-four hours. This was clear, but still much coloured. There remained, therefore, a choice between the three costly materials known to him as being capable of more or less purifying the water, namely, animal charcoal, Spencer's carbide, and spongy iron. Dr. Frankland's well-known experiments on the first of these, the difficulty of manipulating it, and its great first cost, in the form in which it would be suitable at Antwerp, were against it. For commercial reasons, the carbide did not appear fitted for the purpose; whilst his knowledge of the great purifying power of spongy iron, acquired in the laboratory, had induced him to enter upon a series of experiments upon such a scale as was possible in London, with the Nethe water obtained from the river at Waelhem. These experiments, which lasted for several weeks, gave such satisfactory results that he had no hesitation in advising the trial of the process upon the large experimental scale described in the Paper. Mr. Ogston.

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23 January, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

The discussion upon the Paper on "The Antwerp Waterworks," by Mr. W. Anderson, occupied the evening.

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30 January, 1883.

JAMES BRUNLEES, F.R.S.E., President,
in the Chair.

(*Paper No. 1869.*)

"Mild Steel for the Fireboxes of Locomotive Engines in the U.S.A."

By John Fernie, M. Inst. C.E.

The use of mild steel for fireboxes in locomotive engines is now general in the United States. There are still running there engines with fireboxes partly of iron and partly of steel, but the rule, founded on an experience of sixteen years' use, is that mild steel is the most suitable material.

In regard to the outer shells of the boilers, large numbers are yet made of iron plates, but this is to effect a saving of expense. When steel plates approach the price of iron plates, no doubt the whole of the boilers will be of steel. Many railroad companies have the boilers wholly of steel; among these is the Pennsylvania Railroad Company, which has always stood at the head of railroads in America in the adoption of improvements, and whose rolling stock ranks in the first class in America, and indeed in the World.

It seems that iron plates were first used as a substitute for copper in fireboxes in the United States, owing to the rapidity with which the anthracite coal, so much in use there, wore away copper plates; first, mechanically, through the hard sharp edges of the coal impinging against the soft metal, and cutting it away; and, secondly, through the more intense heat evolved from that kind of fuel.[1] Iron plates gave much better results when they were sound; but the difficulty was to get iron plates free from unsound weldings between the slabs of which they were built up. However carefully they might be selected, the

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[1] Minutes of Proceedings Inst. C.E., vol. xlviii., p. 19.

operation of an intense heat, striking through the particles of the iron plates to communicate caloric to the water on the other side, was such a severe test, that it was no wonder there were many complaints about the use of iron. The most frequent failure was from blistering, and when this occurred in a tube-plate there was hardly any other remedy than its removal, which was a labour involving much expense and loss of time, perhaps only to be followed by another failure from the same cause, the uncertain character of the material. Iron plates were also subject to crack near the fire-bars, but the thinner they were (always provided that they could safely carry the working pressure), the more they were free from this fault. Cracks were not, however, the greatest trouble. A crack could be cut out to its further extremity, and a patch of copper screwed on, which would last as long as the other parts of the firebox. Still, notwithstanding the uncertainty about iron, it must be conceded that American engineers, in using this material instead of copper for fireboxes, have long effected a great economy which English engineers have overlooked.

It is no part of the Author's intention to comment upon the various attempts to manufacture mild steel for fireboxes. This part of the subject belongs to the engineers of América; it is sufficient to say that eleven years ago the Author saw steel fireboxes in use on the Pennsylvania railroad, that he procured some samples of the steel, and, by permission of the proprietor of the Black Diamond Steel Works at Pittsburg, saw the whole process of manufacture, and examined the materials of which the steel was made. These samples were exhibited at the Institution.[1] The plates were made of crucible steel, without manganese, and were, according to an analysis by Dr. Siemens,[2] a nearly pure compound of iron and carbon.

Since then most excellent steel for this purpose has been produced by the Siemens-Martin open-hearth process in many places in the United States, and as the manufacture differs from English practice, the Author will describe what he considers to be the best mode of rolling steel plates. The ingots are not hammered. A sufficiently powerful rolling-mill is used, under which the ingots are rolled down to any size and thickness in one heat. The Otis Iron and Steel Company, of Cleveland, Ohio, use a Lauth's rolling-mill for this purpose. This is a three-roll mill, of which the top

[1] Minutes of Proceedings Inst. C.E., vol. xxxix., p. 112.
[2] *Ibid.*, vol. xxxix., p. 112.

and bottom rolls only are driven by the engine. The centre roll is driven by friction with the top and bottom rolls, against which it is alternately pressed during the passing of the ingot. A series of levers attached to the hydraulic machinery, which works the rising and falling tables, raises or lowers the ingot as it passes through the rolls, and also raises or depresses the centre roll. The top and bottom rolls of this mill are 31 inches in diameter, and 112 inches long; the centre roll is 20 inches in diameter. The roughing and finishing are completed by one set of rolls.

The engine is a Porter-Allen engine, with the cylinder 40 inches in diameter, a length of stroke of 48 inches, using steam at 80 lbs. pressure per square inch. It will roll down a 9-inch ingot to a plate 24 feet long and $\frac{5}{16}$ inch thick in four minutes. It makes one hundred revolutions per minute, and is capable of exerting a power of 1,400 HP., when the steam is cut off at one-fourth of the stroke. The whole work of passing through the plates, and bringing down the rolls upon the plates, is done by machinery, except the last pass or two, when the rolls are adjusted by hand for the finishing thickness.

The following specifications for boiler and firebox steel are the last given out by the Pennsylvania Railroad Company to manufacturers:—

"PENNSYLVANIA RAILROAD COMPANY.—MOTIVE POWER DEPARTMENT.

"*Specifications for Boiler and Firebox Steel.*

"All specifications for boiler and firebox steel heretofore issued are hereby annulled, and superseded by the following:—

"1st. A careful examination will be made of every sheet, and none will be received that show mechanical defects. 2nd. A test strip from each sheet, taken lengthwise of the sheet, and without annealing, should have a tensile strength of 55,000 lbs. per square inch, and an elongation of 30 per cent. in section, originally 2 in. long. 3rd. Sheets will not be accepted if the test shows a tensile strength less than 50,000 lbs. or greater than 65,000 lbs. per square inch, nor if the elongation falls below 25 per cent. 4th. Should any sheets develop defects in working, they will be rejected. 5th. Manufacturers must send one test strip for each sheet (this strip must accompany the sheet in every case); both sheet and strip being properly stamped with the marks designated by this Company, and also lettered with white lead to facilitate matching.

"THEO. N. ELY, *Sup't Motive Power.*

"Office of the Superintendent Motive Power,
Altoona, Pa., February 1, 1881."

In the cities of the United States all steam-boilers for stationary engines, or for purposes of raising steam under pressure, are placed under municipal regulations, whereby a proper registration and inspection are instituted at a small cost to the user. In the city of Philadelphia, where there are about four thousand boilers, working under a pressure of, say, 60 lbs. to the square inch, a considerable staff is employed by the department, as each of these boilers has to be personally examined and tested once a year, and, according to this inspection, the pressure which the boiler is considered fit to carry is fixed, and a license is given by the inspector for the use of the boiler for one year at that pressure.

The various formulas under which the calculations are made are as follow[1] :—

"*Formula* A. Pitch of rivets – (Diameter of the holes punched to receive the rivets) ÷ (Pitch of rivets) = (Percentage of the strength of the sheet at the seam, as compared to the strength of the solid part of the same sheet).

"*Formula* B. (Area of the hole filled by the rivet) × (Number of rows of rivets in the seam) ÷ (Pitch of rivets) × (Thickness of the sheet) = (Percentage of the strength of the rivets in the seam as compared to the strength of the solid part of the sheet).

"Take the lowest of the percentages as found by Formulæ A and B, and apply that percentage as the 'value of the seam' in the following Formula C, which determines the strength of the longitudinal seams.

"*Formula* C. (Thickness of the boiler-plate, expressed in parts of an inch) × (Value of the seam as obtained by Formula A or B) × (Ultimate strength of the iron in the plates) ÷ (Internal radius of the boiler in inches) × (Factor of safety) = (Pressure per square inch at which the safety valve may be set)."

When there is no name or brand on the plates of a boiler to indicate its quality, a tensile strength of 40,000 lbs. per square inch of section is allowed, and the inspector "shall use the value assumed with a factor of safety of five (5) in Formula C." This is the lowest test. The highest is when a boiler-plate, from which a portion is cut off lengthwise, and tested in a proper machine, shows a ductility of 20 per cent. upon a measured length of twelve thicknesses of the plate, and will bend cold to 180° over a diameter equal to two thicknesses of the plate, without sign of fracture, and when cut crosswise of the plate will bend cold to 90° over a

[1] "Ordinance regulating the Inspection of Steam Boilers in and for the City of Philadelphia, Pa." Feb. 16, 1882.

diameter equal to five thicknesses of the plate, without sign of fracture, then the lowest tensile strength is assumed as the ultimate strength, and a factor of 4 is used in formula C instead of 5, provided that the workmanship on the boiler is satisfactory.

In every steam vessel navigating the lakes, rivers, or seas, of the United States, and sailing under its flag, a complete system of inspection during the manufacture and an examination when made of boilers is maintained by the Government, and all boiler-plates must be branded with the maker's name, and with the tensile strength of the plate per square inch. Makers of boiler-plates are pecuniarily liable for any failure of their material if it occurs at a lower tensile strain than that with which it is branded. Officers for the examination and testing of materials and work done are appointed, and these may test portions of the plates before they are used, and allow the re-stamping of them, if necessary, with the tensile strain they will bear, provided such strength is not below the least allowable. In regard to marine boilers, fire-boxes of steel have been used for some years with marked success.

The question of testing materials, and of proper testing-machines, seems to be much better understood and practised in the United States than in England. The Government of that country possesses the largest and best testing-machine that has been made. It is now at the Watertown Arsenal, and is after the designs of Mr. A. H. Emery. The highest load put on this machine was 1,000,000 lbs., but 800,000 lbs., or, say, 350 tons, is the ordinary load. The largest section of iron tested was a link 5·04 inches in diameter, that is, say, 20 square inches in section. The machine will test plates or bars 28 feet long, and up to 30 inches wide, and can test links and columns up to 30 feet in length. Efforts are now being made by the American Society of Mechanical Engineers to secure by Government aid such a series of experiments on iron and steel plates, bars, and riveted structures, as will decide many vexed questions concerning the strength of large sections of iron and steel, and which can only be carried out on such a machine as this.

Locomotive engines, which are in one city to-day and in another to-morrow, and which may be constantly moved out of one State into another, can be under no corresponding municipal or Government control. But with systems of control in existence, and a knowledge of the properties of good materials and of how boilers should be constructed, and there being a ready means of testing boilers, a healthy public opinion is formed. This would react on railroad companies, and heavy damages would be obtained

against any company whose boilers exploded because they were made of bad material, or were faulty in construction, or which had run too long without being properly examined.

There is happily in America no Government control to hamper or interfere with railroad engineers, either in regard to the materials which they employ or to their designs. They are at liberty to exercise their ingenuity in construction, disposition, strength, and choice of materials; and the competition between rival companies is so great that the pressure put on railway companies in England to compel them to adopt improvements is not required in America. Inventions are quickly examined, tested, and rejected or adopted; and some of the railways have experimental offices, whose whole work it is to test and experiment on new materials and inventions. With no antiquated ruts or shackles, untrammelled by any official forms or traditions, the American engineer does not accept any type of bridge, machine, boiler, or engine, as the best thing that can ever be made, and which he should slavishly copy and hand down to his successor; nor does he accept materials from manufacturers who refuse to adopt modern improvements. Conservative in the retention of what is best and most suitable for its work he certainly is; but with this conservatism there is the desire to excel, and to receive, as the fruits of his ingenuity, the substantial rewards which the best patent laws in the world give to its inventors.

Before describing the various new forms of American fireboxes, the English type of locomotive firebox will be briefly examined.

First there are two boxes, an inner and outer, made of strong rigid plates, secured together at the bottom by a heavy iron ring, to which both are riveted. Then, to tie them firmly together, strong stays, placed 4 inches apart from centre to centre, are screwed through both the sides and firmly riveted. The spaces between are filled with water, and intense heat is applied to the inner box. The heat passes through the inner box to the water, and, finally, heat is communicated to the outer shell of the firebox. The inner box must therefore be always at a higher temperature than the outer; but at the temperature due to steam at 140 lbs. pressure per square inch, 352° Fahrenheit, the expansion on a 5-feet length of copper would be $\frac{6}{100}$ inch more than on the same length of iron, that is, when both metals are at the same temperature.

Consider, now, the roof of this inner box. To support it, strong iron stays are thrown over it, and every 4 inches a strong bolt-stay, rigidly screwed and riveted, joins the two firmly together.

Here again there is an antagonistic action, arising from the use of two metals possessing a different rate of expansion. These roof-beams are slung from the roof of the outer box, but, however carefully this may be done, it is most unmechanical, as the expansion of the inner box lifts away the bearings of the stays.

But properly to consider the whole of the antagonistic action, it must be understood that the expansion of the copper box is always greater than that of the outer box, on account of the intense heat to which it is subjected. Although it is impossible accurately to tell how much it does expand, yet the action is seen in broken stays, in the collapse of the roofs, in the reduction of the holes in the tube-plates to an oval shape, and in necessitating the adoption of brass tubes, requiring for their support steel ferrules, which obstruct the draught. These brass tubes again, throw an antagonistic action on the boiler, through their ratio of expansion being greater than that of the iron of the boiler.

By the use of copper and brass tubes a galvanic action is established in locomotive boilers, the results of which are seen in the pitting and erosion, continuously eating away and destroying the iron plates. Many serious accidents have thereby arisen.

Seeing then how unscientific and unmechanical the copper firebox is, some of the conditions necessary to make a perfect firebox will now be considered. The Author does not propose to speak of any other shape than the old well-known one; at the same time it may be mentioned that sectional boilers, of which there is a great variety in America, seem to be progressing in favour, but for locomotive purposes the old form yet prevails.

The first requirement for a perfect firebox is that the plates forming the outer and inner boxes should be of similar metal, expanding and contracting alike for similar changes of temperature. As the inner must always be hotter than the outer box, it should be as thin as possible, to allow the heat to pass through its particles quickly. The metal of the inner box must always expand more than the outer, it should therefore be thin enough to bend or spring between the spaces, where it is held by the round stays, and so compensate for the extra expansion it must always bear.

The heavy roof-beam stays should be done away with, not only on account of their unmechanical construction, but because they make it exceedingly difficult to keep the top of the firebox clean. There should be a number of water-tubes through the body of the firebox. The fire-bars should also be water-tubes. If possible the area of the firebox should be largely increased to

avoid the intense heat necessary to raise sufficient steam. For freight-engines, at least, the firebox should be constructed with a large grate area to consume the coal-dust and inferior coal. Finally, the materials should be cheap and easily obtainable.

How far these conditions are obtained in the American firebox will now be considered.

Plate 3 represents a locomotive boiler designed and built at the works of the Pennsylvania Railroad Company at Altoona. This boiler is of a class suitable for the heaviest freight service of the road; it is supported on eight coupled wheels. The weight of the engine is 41 tons in full working order, and it is capable of supplying steam to cylinders 20 inches in diameter and having 24 inches length of stroke. The various dimensions are: grate-bar surface, 23 square feet; heating-surface, 106 square feet; number of tubes, one hundred and thirty-eight; these are 2¼ inches in diameter and nearly 13 feet long. It will be seen that this firebox is entirely different from any English pattern. How near it approaches the conditions of the perfect firebox sketched above will now be demonstrated.

The first condition is fulfilled, the two boxes, the outer and inner, being both of steel.

The outer box is made of steel plates ⅜ inch thick; the sides, where the inner box is most heated, are ¼ inch thick, while the centres of the stays which tie them together are 4½ inches apart, instead of 4 inches from centre to centre.

It will thus be seen that the inner plates would buckle or spring between the stays if a heavy internal pressure were put on, and that such a condition of a light plate thus stayed to a strong one is a near approach to securing a large amount of elasticity between the two unequally-heated plates.

The heavy roof-stays, common to all English locomotive boilers, are dispensed with. This is accomplished by sloping the roofs of the outer and inner boxes to an angle, and by flattening the roof of the outer firebox. By these means flat surfaces are formed through which are passed round stays, and thus the firebox is tied as securely to the roof as it is to its sides. In this instance the firebox falls 1 foot below the level of the barrel of the boiler; this is intended to equalise the weight on the driving-wheels for this particular class of engine. In the Philadelphia and Reading locomotive engines this is not done; no doubt, engines would carry steam much better without this drop.

The water-tubes which pass from the tube-plates to the roof of the firebox carry the fire-brick arch, give circulation to the water,

and add to the steaming powers of the boiler. A considerable number of water-tubes, nine in this engine, twenty-two in the Philadelphia and Reading Railroad engine, are grate-bars. These stand at a considerable angle, and help to send the fuel forward as well as give circulation to the water. Owing to the angle given to the roof of the firebox particles of dirt roll off it, and thus help to keep it clean.

The boilers of the Philadelphia and Reading Railroad Company thoroughly fulfil the desirable condition of increased area of fire-grate surface to burn small coal.

With regard to the comparative cost of the two materials, as steel fireboxes are only half the weight of copper ones, and as the cost per ton of the former is about one-third of the latter, it follows that the actual cost of steel fireboxes is from one-fifth to one-sixth the price of copper ones. It must not, however, be forgotten that the cost of workmanship would be a little more on account of the greater care requisite in working steel.

It is not the Author's intention in this Paper to touch on the subject of economy in fuel. But it must be evident that, with thinner walls, the fuel will produce a greater effect in heating the water. However, the merits of the Wootten boiler as an economical steam generator demand some attention.

The Wootten locomotive, of which there are perhaps now one hundred at work on the Philadelphia and Reading Railroad, is performing a large amount of duty while burning an inferior quality of coal. It is claimed for this engine that the large area of the firebox subjects the plates to very little wear and tear. The fire-grate area is 76 square feet, and the heating surface 167 square feet,[1] being nearly three times as much in an English firebox; consequently the heat, ranging over so much larger a surface, cannot injure the plates as when confined to an area one-third the size. The Author was permitted to examine, while the tubes were out, the first engine of this class which had then run over 120,000 miles. He found it in perfect condition. The Wootten locomotives are now used for the fastest express trains as well as coal trains; they burn the dust of anthracite coal, and can take the heaviest loads with an equal weight of dust, which an ordinary engine would burn of the best coal.

By a modification of the bars the large firebox of the Philadelphia and Reading Railroad has been adapted to burn bituminous

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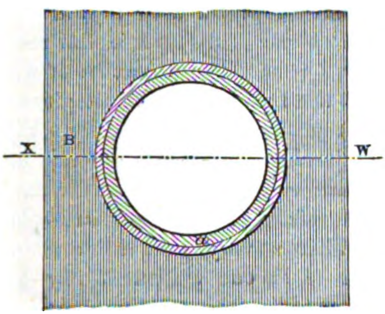
[1] Journal of the Franklin Inst. 3rd ser., vol. lxxxi. (1881), p. 340; also Minutes of Proceedings Inst. C.E., vol. lxv., p. 418.

coal. Plate 4 represents another class of boiler and firebox used by the Pennsylvania Railroad Company. These are all made of steel, but have the heavy beam roof-stays as in the English engines. The steel is the same thickness throughout all the boilers.

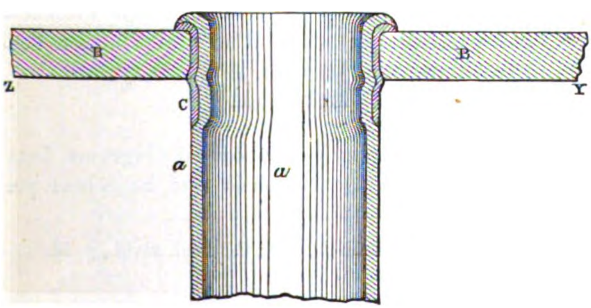
Through the kindness of Mr. Thomson, the General Manager, and Mr. Ely, the Superintendent of Motive Power of the Pennsylvania Railroad, the mileage of these boilers has been furnished to the Author. It is given in Appendices I. and II., from which it will be seen that ninety-three engines with steel fireboxes made a mileage of 20,453,128 miles, equal to 219,926 miles per firebox.

FIG. 1.



Section through Z Y.

FIG. 2.



Section through X W.

HAYES' PATENT TUBE JOINT.

The diagrams (Figs. 1 and 2) represent the mode of securing the tubes in firebox tube-plates. Iron tubes are universally employed; the ends in the firebox have a thin piece of copper brazed on them, after which they are expanded to the form shown in the figures.

In conclusion the advantages gained by the steel firebox over the copper box also includes the use of iron tubes; here also a great economy is effected.

In reference to Mr. McDonnell's views,[1] namely, that "he had tried fireboxes of steel made at Pittsburg, and they did not last as long or pay as well as copper;" it seems he employed thicker steel than is used in America, and no doubt this accounts for his failure. Other engineers have also tried steel fireboxes in England, and have not been successful. This record of existing practice in America may influence steel-makers to produce steel for this purpose, and locomotive engineers to carry out a few more trials of a material which is so successfully and economically employed in the United States.

Samples of the various plates used in the construction of the boilers and fireboxes of the Pennsylvania Railroad are exhibited.

1. The tube-plate, $\frac{1}{2}$ inch thick, a portion of which is bored out for the reception of the tube; also a small piece of tube, of iron, in which at the joint at the firebox end only a thin copper ferrule is brazed on. This joint is universally adopted in America.

2. Roof-, throat-, and end-plates, $\frac{5}{16}$ inch thick. The throat-plate is attached to the lower portion of the tube-plates by means of flanges, between which a very thin liner of copper is placed. Were the whole made in one thickness, say $\frac{1}{2}$ inch, the lower portion would burn out, but this portion being only $\frac{5}{16}$ inch, the heat passes readily through it.

3. Side-plates $\frac{1}{4}$ inch thick. It will be understood that all the other plates, except the tube-plates, could be this thickness so far as strength is concerned, but as the other plates have to be flanged, a little extra thickness, viz., $\frac{1}{16}$ inch, is necessary.

4. Outer shell of boiler $\frac{3}{8}$ inch thick.

The Paper is also accompanied by several diagrams, from which Plates 3 and 4, and the woodcuts in the text, have been prepared.

[1] Minutes of Proceedings, Inst. C.E. vol. xlviii., p. 58.

APPENDICES.

APPENDIX I.

STATEMENT.—MILEAGE of STEEL FIREBOXES in SUNDRY LOCOMOTIVES, PENNSYLVANIA RAILROAD.

Engine Number.	From	To	Mileage.
13	Apr. 1869	Apr. 10 1880	430,677
17	Nov. 1868	July 1876	224,252
24	June 1867	Nov. 23 1875	238,954
27	Dec. 1868	June 8 1880	505,890
31	Oct. 1868	Mar. 8 1878	313,254
40	May 1870	May 10 1877	138,915
55	Nov. 1872	Aug. 17 1878	270,240
75	Mar. 1869	Jan. 1880	248,844
79	Aug. 1868	June 27 1878	202,551
87	Aug. 1868	Mar. 9 1881	224,369
127	Dec. 1866	Jan. 15 1874	114,130
128	June 1870	Dec. 19 1879	204,073
129	Dec. 1869	Aug. 15 1874	95,620
133	Oct. 1868	Jan. 8 1880	497,914
136	Apr. 1869	July 10 1880	233,848
152	Oct. 1872	Aug. 23 1881	343,416
161	May 1869	Feb. 12 1880	281,275
166	Nov. 1872	June 12 1879	191,969
183	Feb. 1870	Oct. 19 1877	216,388
193	Feb. 1870	May 9 1878	335,304
219	May 1870	Mar. 5 1880	207,653
273	Sept. 20 1875	Oct. 25 1880	251,552
281	Oct. 1872	Oct. 5 1881	218,071
314	Nov. 6 1877	Apr. 6 1881	128,443
337	Oct. 12 1875	July 1879	133,583
338	Aug. 1868	Sept. 24 1878	318,707
345	May 1865	Sept. 21 1881	179,274
351	Apr. 27 1876	Sept. 12 1881	161,297
358	Dec. 1866	May 5 1875	203,339
366	Jan. 1866	June 13 1872	155,500
379	Dec. 1866	Aug. 18 1874	199,115
380	Dec. 1866	Apr. 3 1872	171,036
382	Dec. 1866	June 12 1875	236,166
421	Sept. 1867	July 1 1876	246,919
422	Sept. 1867	Oct. 4 1880	439,539
423	Oct. 1868	June 6 1879	325,881
424	Oct. 1868	Jan. 17 1877	239,702
425	Oct. 1868	Sept. 3 1880	307,809
427	Nov. 1868	Mar. 1880	302,621
428	Nov. 1868	Aug. 29 1881	449,628
449	July 1869	Apr. 4 1877	279,882
451	July 1869	Apr. 4 1881	300,300
455	Oct. 1869	June 21 1877	190,999
460	Nov. 1869	Jan. 4 1878	201,515
463	Dec. 1869	Jan. 1 1877	219,376
465	Dec. 1869	Jan. 10 1878	225,719
468	Aug. 1869	Nov. 1875	144,902

APPENDIX II.

STATEMENT.—MILEAGE of STEEL FIREBOXES in SUNDRY LOCOMOTIVES, PENNSYLVANIA RAILROAD.

Engine Number.	From		To		Mileage.
480	Jan.	1870	Oct. 15	1880	239,306
481	Feb.	1870	Aug. 18	1877	204,321
482	Feb.	1870	Apr. 2	1878	218,542
484	Oct.	1871	Apr. 12	1880	229,692
485	Oct.	1871	May 18	1877	170,638
489	Nov.	1871	June 30	1881	363,496
492	Nov. 12	1871	Sept. 17	1880	245,921
504	Aug.	1871	July	1877	185,738
508	Sept.	1871	Feb.	1878	262,099
533	Apr.	1872	Oct. 4	1880	219,415
537	Apr.	1872	July 30	1880	302,424
540	May	1872	Apr. 30	1879	194,842
543	May	1872	Aug. 12	1879	220,607
544	May	1872	Apr. 30	1880	183,032
563	Dec.	1872	Mar. 27	1880	207,682
565	Dec.	1872	May 19	1880	136,410
566	Dec.	1872	Sept. 26	1879	168,801
627	Nov.	1872	Apr. 4	1879	195,754
786	Nov.	1872	Jan. 5	1878	154,261
791	Apr.	1873	Dec.	1876	65,860
805	Mar.	1873	July 30	1881	234,350
813	Apr. 14	1873	Mar. 31	1881	159,700
815	Apr.	1873	Feb. 13	1880	162,151
821	May	1873	Dec. 31	1880	182,483
823	May	1873	June 11	1880	193,489
827	May	1873	Feb.	1880	153,654
828	May	1873	Apr.	1878	175,610
829	May	1873	Apr.	1878	169,872
833	June	1873	May 31	1881	172,827
835	June	1873	Apr. 27	1881	242,396
837	June	1873	Dec. 30	1879	180,196
839	June	1873	Feb. 25	1880	167,977
840	June	1873	Feb. 20	1880	178,832
842	July	1873	Aug. 26	1880	207,229
844	July	1873	Nov.	1880	272,931
850	July	1873	Aug. 26	1881	204,221
855	Aug.	1873	Aug. 24	1881	222,022
857	Aug.	1873	June 18	1881	169,312
859	Aug.	1873	Nov. 25	1881	190,988
860	Aug.	1873	Feb.	1878	143,884
861	Aug.	1873	Sept. 11	1880	237,225
864	Aug.	1873	Jan. 30	1880	192,962
865	Aug.	1873	May 19	1880	178,218
871	Sept.	1873	Mar. 25	1880	148,892
912	May	1873	May 21	1880	236,368

Discussion.

Professor A. B. W. Kennedy said that the question of the Pennsylvania Railroad's steel fireboxes had been discussed before the Institution in 1874. It might be remembered that there then seemed to be something a little mysterious about the steel which, it was said, American engineers had been successful in using—at least no clear account had been given of what it was and how its quality was ascertained. It was therefore with some curiosity and a great deal of interest that he had turned to the present Paper in the hope of finding out something about this material, which for some reason or other had not proved satisfactory in the hands of English engineers. It was with great surprise, therefore, that he had read the Pennsylvania specification, and had found also that this specification was by no means peculiar to that railroad. He held a number of recent official tests of the New York and Lake Erie Railroad, whose results corresponded exactly with those given by the Author. It appeared from the specification that both boiler and firebox were to be of steel which had a tensile strength of not less than 22½ tons, and not more than 29 tons per square inch, with a ductility corresponding to an elongation of 30 per cent. in 2 inches. The New York and Lake Erie Railroad showed exactly similar quantities. It was stated at the former discussion that a different steel was necessary for fireboxes from that required for boilers, and at that time also it seemed usual to submit the firebox plates to repeated quenchings and various temper tests. All difference of tests between shell and firebox plates seemed to have now disappeared, as well as all tests of softness in either case. There was left nothing more than a specification in tenacity and extension, of which English engineers could pretty well judge, because makers here now supplied a material more or less similar. Certainly, steel made by the open-hearth process, which had a tenacity of 24 tons and an elongation of 30 per cent. in 2 inches, was a sort of thing well known in this country. He had taken the trouble to make a memorandum of a few averages, which he thought might be interesting, for the purpose of showing that whatever might be the cause of want of success in making steel fireboxes here, it could not be that a material in every respect excelling that specified in America was not available. The mild steel open-hearth boiler-plate that was used by English engineers had a tenacity of about 30 tons, and an extension in 2 inches of about 45 per cent., and Prof. Kennedy.

Prof. Kennedy. 24 per cent. in 10 inches. One of the largest bridges now being made was being built of similar material, which had a tenacity of 29½ tons and an extension of 38 per cent. in 2 inches, and 21 per cent. in 8 inches. If the tenacity were to be lowered to 24 or 25 tons, 55 per cent. of extension in 2 inches could be obtained, and 28 or 30 per cent. in 8 or 10 inches. If, on the other hand, as little extension as was specified in America was sufficient a much greater tenacity could be got. The ordinary tire-steel, for example, used in this country and elsewhere, taking a number of qualities and a number of makers, ran to about 40 tons per square inch, with an elongation of 24 per cent. in 3 inches. He gave those figures, as they happened to be within his own personal knowledge, and as they represented what was done in this country on a large scale every day, and not any special or exceptional results. He really felt inclined to describe the material to which reference had been made as one which had the ductility of hard steel and the tenacity of wrought iron. With regard to some of the formulas given in the Paper, he hoped that English engineers would no more be found copying them than the steel specification. They were the regular old schoolboy formulas got out mathematically without regard to the actual values of the constants which had been repeatedly found to be necessary in such cases; and they were particularly inapplicable to any construction in steel. He knew from the work which he had had the pleasure of doing with a Committee of the Institution of Mechanical Engineers that they would give results that were exceedingly inefficient. He would not, however, go further into the matter than to say that they assumed the shearing resistance of rivets was taken as equal to the tenacity of the plates, and that the gain of strength in perforated steel bars was entirely neglected. After all this he thought that the sentence about testing in America could hardly be taken seriously. He hoped that Sir Frederick Bramwell might redeem a half-promise made some time ago, and give an account of the Watertown machine. But it was only right to point out that it was entirely incorrect to say that the American Government had the largest testing-machine that had been made. Surely all English engineers knew of Mr. Kirkaldy's machine, which was of exactly the same size, and which had worked successfully for so long. There was also another exactly similar machine at Malines, the property of the Belgian Government, and used in connection with the Belgian Government railways. Both of them had been made by Messrs. Greenwood and Batley; so that English engineers were really not very much behind the age

in that matter. He could not quite follow the Author's reason in regard to some matters connected with the expansion of fireboxes, and the arrangement of the stays; but in his absence he would not enter into those subjects. The question of the design of the fireboxes would be very much better handled by other persons, but with reference to the question of material, it appeared to him that there was in England a material to all appearance equal to that used in America: if, therefore, it was found advisable on other grounds to use steel in fireboxes, there were the means ready at hand of doing so with great success. Unless he was quite mistaken, in fact, the firebox-steel now used on the Grand Trunk Railway of Canada, where steel was as successful as on the American lines, was actually open-hearth Siemens steel made in Scotland. Prof. Kennedy.

Mr. EDWARD REYNOLDS thought that Professor Kennedy had lost sight of the whole scope and object of the Paper. It was not intended to show how strong steel could be made, but rather to throw some light upon the reason why steel fireboxes answered in America and not in England—why the strong material to which Professor Kennedy had alluded did not appear to stand in fireboxes. There were certain causes for it, one of which was to be found in the more square shape of English fireboxes and their large size. The troubles with locomotive fireboxes did not exist, at any rate to any appreciable extent, when they were 3 feet square. Some of the things which had been supposed to be novelties were old tales to many of those present, as, for example, the direct roof-stays with sloping fireboxes. The earliest engines on the Great Northern Railway were so made. He knew that Mr. McDonnell had made comparative trials of American and at least two makes of English mild steel for fireboxes, and, without having had a full report, he had reason to believe that one of the English makes had proved superior to the American steel, but that the result of the whole experiment was unsatisfactory. That might have been from the cause indicated in the Paper; that it was too thick, instead of being made so thin that it could accommodate itself to unequal expansion by buckling. He might mention another thing with reference to the difference between the old and the new practice. About the time Mr. McDonnell ordered the material several fireboxes were ordered by the Caledonian Railway Company, and by the North British Company, on account of the success of some engines, which he believed were still working well, and which were fitted with so-called homogeneous metal fireboxes, by Mr. Allan, at Perth. The result of the experiment with the material ordered, and supposed Mr. Reynolds.

Mr. Reynolds. to be identical, was disastrous. Mr. Reynolds asked the locomotive engineer of the Caledonian Railway for some specimens of the material of the old successful fireboxes, and he was kind enough to get the engines at Perth, and send him some chippings from the bottom of the fireboxes and punchings, which had been preserved from the time they were made. They were by no means of very soft steel; they contained more than 0·3 of carbon; they were otherwise very pure. He thought the difference in durability was chiefly to be found in difference of size. A small firebox could not be subjected to so great a variation of heat in different parts, and, even if this were possible, the extent of the inequality of expansion would be proportional to the size; and if plates of the large size now required must be rigidly fixed, engineers must aim at the use of a steel possessing many of the qualities of copper, which was so ductile that it would bear alternate extension and compression without rupture for a considerable period; but probably the best course was to do what was indicated by the Author —to take a thinner material, and provide for its buckling. It was not possible to make a locomotive firebox on the principles of Fox's corrugated circular firebox, and the nearest thing that could be accomplished was to provide for buckling.

Mr. Paxman. Mr. J. N. Paxman said that four years ago his firm began to manufacture steel fireboxes, and up to the present time had made two hundred and thirty with very fair results. They found that steel bearing 25 tons tensile strain per square inch was about the best for the purpose. It gave a larger percentage of elongation. In 1872, at Cardiff, a firebox was shown by them with water tubes, so that they were not quite new.[1] He agreed with the Author that the plates ought to be tolerably thin, but he thought $\frac{1}{4}$-inch plates were certainly too thin, especially at the part where they were riveted to the ring at the bottom, because at that part of the boiler oxidization took place quickly. He had always advocated thin plates, but there were persons who, in specifying boilers, were determined to have thick ones, so that makers were somewhat cramped in that respect. They found, however, that plates $\frac{3}{8}$ inch thick and tube plates $\frac{1}{2}$ inch gave perfect satisfaction. With regard to ferruling the tubes, he might mention that for nearly twenty years they had made boilers without ferrules. They expanded the tubes, and swelled them out inside and also at the outside, but never had recourse to ferruling. There was a little

[1] Journal of the Royal Agricultural Society of England. Second Series, vol. ix., p. 66.

more difficulty in getting the tubes out, but that was not very important. The steel used was made by the Siemens-Martin process, and also brought from the forge works, and both those samples had given great satisfaction. Up to the present time they had not had a single mishap with these fireboxes, and they were now using steel entirely. He was satisfied that this would be the future material for fireboxes. His firm were using it for boilers, working up to 150 lbs. per square inch. There were two boilers now working from 120 to 150 lbs. pressure per square inch at Nine Elms Station, the boilers and the fireboxes being both of steel. At the Aquarium another boiler of the same kind had been put in for the Electrical Exhibition, and that would sustain the same pressure. In that case, the boiler and the firebox were, like the other, of steel. There were seven or eight boilers at the Aquarium, and all of them had steel fireboxes. The tubes were fixed without ferrules, and the tops of the fireboxes were stayed or tied to the crowns of the boilers. He agreed with the statement of the Author with regard to roof-stays. The old system of roof-stays for fireboxes was rather a bad one. He thought that fire-boxes should be, as far as possible, suspended to the crown of the boiler, and he believed that in good English practice that method was generally adopted. Some locomotive engineers would perhaps be able to state their experience, and if it had led them to reduce the number of roof-stays by adopting the principle of suspending them to the top of the boiler. He could not help thinking that the large firebox illustrated must be a difficult one to keep clean at the top unless the water was exceptionally good; but where the water was bad, they would get incrusted and become troublesome. No doubt the circulating tubes would assist, but even those, twenty in number, would be inefficient to keep the firebox clean. The small boiler before mentioned, and shown at Cardiff, had, he believed, ten small iron bent tubes which behaved well. He had not followed out their adoption because there seemed a prejudice against them, owing to their diameter being small and incrustation taking place rapidly, and they were also more difficult to get at for repair. Mr. Paxman.

Mr. S. Earnshaw Howell said, that as his firm was the first to manufacture steel sufficiently mild to make into shapes like fire-boxes, it might be thought that he was in a position to give some slight account of the use of steel fireboxes in England. It was about the year 1860 when steel fireboxes were first used in this country. They were then put into certain engines referred to by Mr. Reynolds by Mr. Allan, on the Scottish Central Railway. Mr. Howell.

Mr. Howell. Some of those engines were, he believed, still running. He had a letter from the late Mr. Connor, Locomotive Superintendent of the Caledonian Railway, stating that the fireboxes which were put in between 1860 and 1863, were still working in 1871, and only two out of ten had been slightly repaired. The tube-plates were $\frac{5}{8}$ inch thick, and that the back-plates were $\frac{3}{8}$ inch thick. Though Mr. Allan had put in some side-plates $\frac{3}{8}$ inch thick, the majority of those plates were $\frac{5}{16}$th inch. Mr. Allan also stated that he had put in tubes between the back- and the tube-plates; he found that the engines did not steam well, and he consequently inserted those which produced a much better steaming power. The tubes were just over the firebars, 15 inches by 5 inches at the back end; at the front end, 10 inches by 5 inches. The plates were of mild steel, and they had given satisfaction. In 1870 or 1871 Mr. Connor was induced to make a further trial of mild steel plates, and contrary to their desire, he used a much thicker plate than in the earlier fireboxes, and other engineers followed his example. The majority of the tube-plates he had used were $\frac{3}{4}$ inch thick back-plates, $\frac{1}{2}$ inch and $\frac{7}{16}$ inch, and though there were some $\frac{3}{8}$-inch side-plates, others were $\frac{1}{2}$ inch. They had, therefore, come to the conclusion that the plates failed chiefly because they were too thick; the fire over-heated them, and when the fire-door was open a rush of cold air came on the plates, which contracted rapidly, and consequently cracked with loud reports. He believed, if the plates had been as thin as the former ones, the fireboxes would be still running. Another cause of their failure, he thought, was due to the flanges of the plates being bent at too small a radius for the thickness of metal, which caused them to crack. Moreover, the steel plates had been annealed. If an attempt were made to break a piece of mild steel nicked across it, it would bend and draw without breaking, whereas a similar piece of steel annealed, with a nick in it, would break short off; consequently, if there were any burrs or starting places for the plates to crack, annealing would aggravate the evil. The American tests had already been referred to as common in this country, and he might say that all the plates which his firm had had the pleasure of sending out, would have stood any of the tests required in America. If the boiler, the firebox, and the tubes, were made entirely of steel—one metal throughout—there would be less chance of galvanic action, which seemed to him a matter very much overlooked in the designing of locomotive boilers. It was well known that there was galvanic action between copper and iron or steel. Mr. Farquharson, as stated in the Transactions of the Institution of Naval

Architects,[1] had made some experiments in Portsmouth harbour, with regard to that action between steel and iron. It was well known that salt water had a greater galvanic action[2] than ordinary water; but Mr. Farquharson had put various iron and steel plates into the harbour, and he had found that the corrosion on the iron plates was somewhat similar to that on steel—rather in favour of the iron than of the steel. He then took an iron plate and a steel plate, and joined them together with an iron bar, and the consequence was that the galvanic action caused corrosion in the iron plate in excess of that of the steel one in the proportion of 15 to 1. He believed that on the whole it would be better to use steel tubes than iron tubes, in steel boilers. Copper fireboxes were generally adopted in English locomotives; great economy, therefore, might be obtained by the use of steel or iron tubes coated with copper, thereby diminishing galvanic action. An advantage of using steel or iron tubes coated with copper, instead of solid copper or brass tubes, was that there was little wear in iron or steel by the action of the fuel in comparison with solid copper or brass, which were rapidly decomposed and worn away. Another advantage was that copper-coated tubes could be used much thinner than the solid copper or brass ones, and at about half the cost. Mr. Howell.

Sir FREDERICK BRAMWELL, Vice-President, said he believed there were three matters in the Paper which might be taken under distinct heads. One, which agreed with the title of the Paper, was mild steel for the fireboxes of locomotive engines; another the testing machine at Watertown; and the third the Patent Laws of the United States. The last, he thought, had better be left to another place, as he did not suppose that he should have a very sympathetic audience if he now indulged in a speech upon it. With regard to the subject of steel for fireboxes, he might state that he had had an opportunity of a very lengthened inspection of the workshops of the Grand Trunk Railway at Montreal, through the kindness of Mr. Herbert Wallis, M. Inst. C.E. The engines were made on the premises, and the fireboxes were very similar to those mentioned in the Paper. The internal boxes were of steel plates, which were only $\frac{5}{16}$ inch thick. The staying of the roofs of the boxes was sometimes done by roofstays, but much more commonly by stays connecting the top of the internal Sir Frederick Bramwell.

[1] Vol. xxiii., 1882, p. 143.

[2] "A Singular Case of Corrosion of Steel." By Prof. C. E. Munroe. *Post*, Foreign Abstracts.

Sir Frederick Bramwell. box with the top of the external box. The boilers carried as high a pressure as 160 lbs. per square inch in regular work. The engines had 18-inch cylinders, with a 26-inch length of stroke, four wheels coupled; and their tractive powers were very great. The reason given to him for the employment of engines of such power was that it was economical to have very heavy trains and very few per day. He was told that it was preferable rather to run the risk of a train sticking, and having to be cut in half, than to multiply the number of trains. There was no doubt that upon those grounds the engines were very heavily worked, but nevertheless the fireboxes appeared to be perfectly satisfactory. These boilers had also wrought-iron tubes fixed into the tube-plate by means of a copper thimble. An expander was used; the wrought-iron tube was left projecting far enough to be turned over by the expander, so as to conceal the copper from the action of the fire, and so as to prevent the tube drawing through the thimble. At the smokebox end there was no similar thimble, and, he thought, no ferrule, the tube being merely set out by the expander. One thing that interested him very much was the mode of repairing the damaged tubes. The tubes, as would of course be expected, were worn first at the firebox end. When that happened, they were taken out, and the injured piece was cut off in a lathe; the end was expanded, and then the end of a short piece of tube was inserted; it was heated in a forge, and put under a mechanical hammer, worked by a cam, making several hundred blows in a minute. In that way a new end was welded on to the tube, and the whole cost of taking out the tube, scaling it, cutting it, and welding on the new end was 13½*d.* a tube. Many tubes had been repaired in that manner seven or eight times. That was one of the things that had struck him most at the works. The circulation tubes carrying a brick arch were not used, as he was sorry to say there was no brick arch. They had been tried, but the officials could not get them attended to, and therefore gave them up. The result was the most disgraceful smoke that he had ever met with upon any railway. He did not mean to say that it belonged to the Grand Trunk Railway only. It was the defect of all the railways where anthracite was not burned. As a matter of fact, the front door of the ash-pan was open the whole time. The fire-door was not open at all. The whole of the air for combustion went through the body of the fuel, instead of a large portion going over the top and burning the gases. It appeared to him that the practice of the Grand Trunk Railway entirely corroborated all that was stated by the Author.

He might mention that Messrs. Davey, Paxman and Co. had, at the Royal Agricultural Society, many years ago, the last occasion on which he officiated as judge, a vertical boiler, wherein there were circulating water-tubes from the lower to the upper part of the firebox, and they appeared to give very good results. According to his recollection their evaporative duty was not quite as high as some of the very best boilers of the locomotive type, but they were extremely compact and light. If the duty was not as high, the difference was only some small fraction of a lb., not worth taking into consideration. He was pleased with the boilers, and he was sorry to hear, in the course of the present discussion, that the firm had found a difficulty with them where the water had not been good. With reference to the proving-machine at the Watertown Arsenal, near Boston, he went to see that machine, and there, as always in the United States, he met with every possible amount of attention and cordiality, and all was shown and explained; indeed, it was impossible to speak too highly of the way in which an English engineer was received in the United States. The Watertown proving-machine was, he thought, one of the most beautiful pieces of mechanism he had ever seen in his life. The conception of it was of the hardiest; indeed, he believed that had the plan been submitted to any member present, he would have said, "It is very good indeed upon paper, but it will never work." But it did work. The plan consisted in transmitting the pressure of the operative part of the press on to the registering machine by means of a fluid connection, the abutment of the part of the machine holding the specimen under compression, or extension, was made against flat closed cylinders, four in number, containing glycerine and a little alcohol, upon the flexible ends of which cylinders the whole pressures came. Pipes, no larger than a straw, conveyed that fluid pressure from these cylinders to similar, but very much smaller cylinders, which worked the registering machine. By this arrangement, the actual pressure upon the specimen was reduced by the proportion of the area of the different cylinders by the time it got to the registering machine. It was then further reduced by levers; none of the levers in the machine, however, acted upon knife edges, but by means of an almost immeasurably small flexure of a blade-spring. The result was a frictionless testing machine, and one of the handiest possible description. The experiments were made very rapidly, and the person registering sat opposite the front of a glazed case, in which were the various rods lifting small weights, indicative of the strain on the specimen. When any particular pressure was

Sir Frederick Bramwell.

Sir Frederick Bramwell.

reached, the rod carrying the small weights agreeing therewith was lifted. The reading, which was unmistakable, was made in a moment, and the experiment was over almost before one knew that it was begun. He was told that when the machine had been put through the greatest test to which it had been subjected (about 370 English tons of 2,240 lbs.), it was, in order to ascertain whether the machine had suffered at all, used to try the tensile strength of a horsehair, which strength was duly registered. He might mention that, without any difficulty, by pushing against the abutment, he was able to show upon the index of the machine the pressure he was exerting, although that very machine had been immediately before used in his presence for putting a considerable number of tons upon a wooden column that was broken for his inspection. The fluid that was employed in the press was oil, the pressure being derived from an accumulator, charged by a pump worked by a small donkey-engine. The press itself moved, and the supply of oil was made by a system of articulated pipes (which were perfectly tight at all their joints), allowing the free and independent movement of the press. As he had already said, he thought if the plans had been submitted to any one, and he were asked to approve of them, he would have said that they demanded, as a condition of success, such superexcellent workmanship that it would be idle to adopt them, and the thing would never answer; but there the machine was in efficient use, thanks to the perfect workmanship bestowed on it. He could not state exactly the nature of the material used for the so-called steel fireboxes, but he had no doubt that the steel in question was of the very mildest character, such steel as was produced at the Landore works, a material with which, if a boiler were constructed, it might be made to leak, but it could not be blown up. He had been recently using Landore steel for the purpose of air-vessels to carry air 450 lbs. to the inch regularly, and he thought it was worth while, before doing so, to have some samples of riveted joints made of the steel, and to get them tested by Professor Kennedy at University College. The result of that testing was to convince him that one might as well endeavour to burst, explosively, a leathern bottle. The rivet-holes might be elongated, and be made to leak, but he did not think it was possible the vessel could be burst. He had very little doubt, from the way in which the material he saw at Montreal worked, that it was about as supple as metallic leather—if such a thing could be imagined. Being only $\frac{5}{16}$ inch thick, there could be no doubt, as Mr. Fernie had said, that it was competent to accommodate itself to those

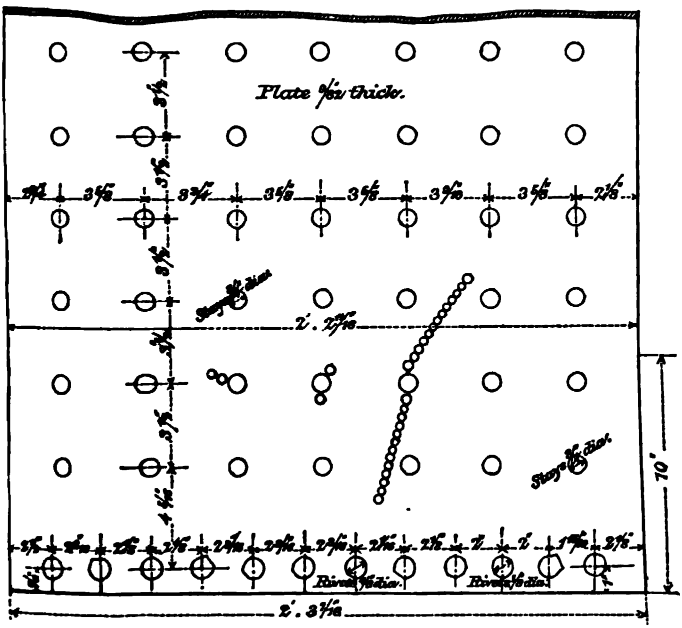
Sir Frederick Bramwell.

changes of temperature which arose within the fireboxes, having regard to the intense anthracite fire therein, although, as he had also pointed out, the larger grate surface no doubt diminished the intensity that would have prevailed in a smaller box.

Mr. Thornycroft.

Mr. J. I. THORNYCROFT said his experience of steel fireboxes was very limited. His firm used steel for the outside shells of boilers, and now almost exclusively iron for the boxes; but when the subject of steel boxes some years ago excited a great deal of

FIG. 3.



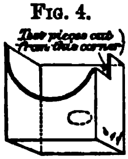
CRACKED STEEL FIREBOX PLATE OF SHOP BOILER IN USE FROM 1875 TO 1880.
Scale ¼ inch = 1 foot.

interest, they erected at the works a boiler having a steel firebox which was $\frac{9}{32}$ inch in thickness, but only of about 2½ feet by 3 feet (Fig. 3). The box worked five years, and towards the end of that time it developed some cracks. They each seemed to have their origin at a stay-hole, but they did not immediately make as it were for another stay-hole, but cracked in an oblique direction, more nearly vertical than horizontal. There were five cracks, and they all started from stay-holes situated 5 or 6 inches from the fire-bars, about the part of the box which was exposed

Mr. Thornycroft.

to the greatest heat. The boiler was ordinarily worked with a natural draught, but as the demand for steam on it was increased, it was found necessary sometimes to force a little air under the ash-pit to increase its power. Whether the boiler would have continued to stand with the natural draught or not was uncertain, but it finally cracked. One crack was 1 foot long, and some of the other cracks were from ½ to 1½ inch long, in each case starting from a stay. That seemed to indicate that the metal was distressed by the action of the stay being riveted or too tightly screwed into the box. The thickness of the box was only slightly greater than that recommended by Mr. Fernie, but the staying was more close. The stays were about 3½ inches in one direction, by 3¾ inches in the other. The plate near the bottom ring of the boiler was a good deal less than ¼ inch thick; whether that was due to corrosion or not he did not know. Through the kindness of Professor Kennedy he had had a part of the box tested, and his experiments had shown that the material was very tough. Previously he had himself tried a piece of the plate, and the part broke from it with a very brittle fracture, quite unexpectedly, but the specimen tested by Professor Kennedy showed an extension in 4 inches of 27 per cent. The ultimate breaking load was 31 tons per square inch, and the limit of elasticity 15·82 tons. Professor Kennedy's Report was as follows:—

FIG. 4.



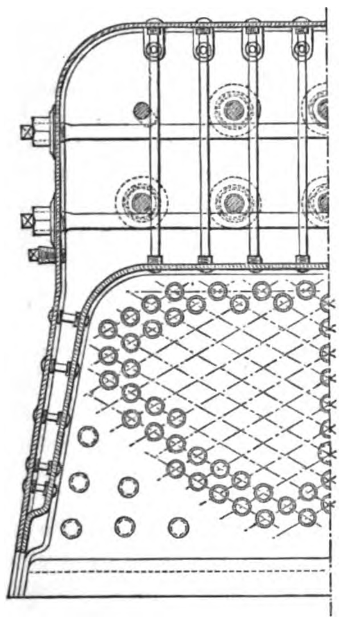
Scale ¼ in. = 1 ft.

U.C.L. Test Number.	Marks on Piece.	Dimensions.			Limit of Elasticity.		Breaking Load.		Ratio of Limit to Break.	Extension on whole length of 4 inches.	Reduction of Area at Fracture.	Remarks.
		Breadth.	Thickness.	Area.	Pounds.	Tons.	Pounds.	Tons.				
		Inch.	In.	Sq. In.	Per Sq. Inch.	Per Sq. Inch.	Per Sq. Inch.	Per Sq. Inch.		Per cent.	Per cent.	
3788	None	1·992	0·309	0·615	35,440 (Not very distinctly marked.)	15·82	69,500	31·03	0·510	27·0	44·2	Fine and silky, uniform.

The steel, he supposed, was stronger than that recommended in the American practice, but it might be that the sulphur in the fuel had hardened the steel, and possibly it was not originally so strong. The fracture was silky. It had always appeared to him that in very thin steel plates the metal was tougher and more leathery, as described by Sir Frederick Bramwell, than in thicker plates. It might be that there was a double advantage in using very thin plates for fireboxes, the one being that the material was better, and the

other that it was more elastic, and more liable to buckle; and he thought that perhaps the plate of the firebox might be corrugated, as in Fox's flues, with advantage. There was one thing their experience of fireboxes had led him to expect would be an advantage; if nuts on the stays in the firebox could be used (if they would not burn away too fast) instead of riveting them, local distress would not be put on the plate in the neighbourhood of the Mr. Thornycroft.

FIG. 5.



FIREBOX OF LOCOMOTIVE BOILER FOR 2ND CLASS TORPEDO BOAT.

Scale ¾ inch = 1 foot.

holes. There was a remark in the Paper under discussion as to the great advantage of the form of firebox with the plate-stays very near the corner. His firm had used boilers with a good large radius in the corner, and also in the roof of the fireboxes, and it appeared to him that that construction gave greater elasticity, or rise and fall of the boxes, than the vertical construction, but he thought there could be no doubt as to the advantage of staying the box to the boiler plate. One advantage that he saw in the American locomotives was the large grate-surface used. Trouble arose in locomotive boilers from the small surface and the very large amount of heat to be absorbed by the surface. It was

Mr. Thornycroft. well known that a large proportion of the heat was absorbed in the firebox, and if the area of the firebox could be increased, the work to be done would be lessened for each unit of surface. Probably, also, the temperature in the firebox would be lessened, and if small coal could be used with the same advantage as lump coal, it would be economical, being, to some extent, a waste product.

Mr. McDonnell. Mr. ALEXANDER McDONNELL was sorry he was not in a position to contribute much information upon the subject. He did not think the trial which he gave to the steel fireboxes was enough to prove distinctly the advantage or disadvantage of that material. So far as his experiments went, they showed that with English systems of locomotives the copper firebox was the best. He had tried three fireboxes. One of them was in a stationary boiler, and two of them were in locomotives as like as possible to each other. One was made of steel that he had got from Messrs. Park Brothers, Pittsburg, U.S.A.; one was by Howell's, and another by Vickers's. The box made of Howell steel was in a stationary boiler. It was difficult, of course, to institute any comparison with regard to that, and his only attempt at comparison was by the number of hundredweights of coal burned by it as compared with the number of hundredweights burned by the locomotive. The mileage of the box made of American steel was 102,966; the box of Vickers's steel ran 171,309 miles; a copper box, in a sister engine, burning the same kind of coal, ran 296,622 miles. He had taken that copper firebox as a sample because it was worn out, but he had a great number of fireboxes in copper, in a similar class of engines, which had run a much longer mileage; so that the sample he had selected was rather a bad one, and not an average one; it was certainly below the average of the mileage of copper boxes on the Great Southern and Western Railway, using coal from South Wales. The quantity of coal used in the American box was 19,270 cwt.; in the Vickers's firebox, 34,765 cwt.; in the stationary firebox, made of Howell's steel, 26,000 cwt.; and in the copper firebox 50,084 cwt. Both the American steel and the Howell steel cracked; in the one case in the tube plate, and in the other case in the sides underneath the firebrick arch. In the case of Vickers's steel, the box did not crack, but was worn very thin immediately over the foundation ring at the bottom of the firebox. He had analyses of the American steel and of the Howell steel, but not of Vickers' steel. The analysis of the Howell steel was—carbon, 0·38; manganese, 0·119; phosphorus, 0·32.

The analysis of the American steel was—carbon, 0·33; manganese, a slight trace; phosphorus, 0·51; silicon, 0·108. The American steel was soft enough to bend double when cold, but by the quantity of carbon in it he did not think that it could now be considered as an exceedingly soft steel. With regard to the question of the steel being thicker than was commonly used in America, before he tried any experiment he sent a tracing of his firebox to Messrs. Park Brothers, and asked if they could suggest any improvement in it, or in the thickness of the steel. They told him that the practice in America was to use thinner steel, but they did not see any objection to the box he proposed, and they afterwards sent him the plates for it, which were $\frac{3}{8}$ inch thick, the tube-plate being $\frac{5}{8}$ inch. With regard to the form of construction, it was of course a very easy thing to criticise a firebox; but it was a great deal more difficult to make a better one, and in constructing a boiler to carry 140 to 150 lbs. pressure per square inch, one felt a little nervous about putting in $\frac{1}{4}$-inch plates, thinking that if a little of it was worn away it might become slightly dangerous. Of course it was a great advantage to have the contraction and expansion of the material the same in the outer and in the inner shell. In the use of steel boxes, and iron or steel tubes, it ought not to be overlooked that a good deal more labour was required to keep the tubes and fireboxes from leaking. One of the things that he was greatly troubled with, in the steel boxes, was that the tube-plate yielded all at once. The driver, in the middle of a journey, heard a crack, and all the tubes in the box began to leak, as if the friction between the tube and the tube-plate was not sufficient, the whole tube-plate moving suddenly and giving way. He tried to correct that by substituting for some of the tubes stays from one tube-plate to the other. That answered to a certain extent, but not altogether. He was still troubled by the tubes suddenly commencing to leak, and that continued until he took out the steel tubes and put in brass tubes. He thought the American practice showed that there was a difficulty where the tube-plate was of steel. He thought there must be a different material in the tubes and in the tube-plates, to cause a sufficient amount of friction to hold the tubes properly. The question of the roof-stays was a matter upon which he should like to hear the opinions of others. He had always used the beam-stay on the top of the box, and he admitted that he was in favour of it. He had not seen any box stayed from the roof in the other way that he was very well satisfied with. The difficulty of getting the stays in, with a round top to the firebox, in a satisfactory way, Mr. McDonnell.

Mr. McDonnell. was very great. Making the plates of the firebox exceedingly thin, and keeping the roof-stay in the girder form, would probably lead to much difficulty. One point to aim at now certainly was to keep the top of the box well up. If the sides of the box were thinned in such a way that they would not support the roof-stays, the support that the roof-stays ought to have was removed, and recourse must be had to more sling-stays, which were very difficult to get in. He had not had time to calculate exactly, from the mileage, the cost in pence per mile for a copper and a steel box, but he thought the old copper box was not much more expensive than the steel box. The cost of the fireboxes, with the miles they ran, and the cost in pence per mile, was:—

Number of Engine.	Firebox made by	Cost per Ton.	Cost per Box.	Miles run.	Cost per Mile.
		£.	£. s. d.		d.
25	Messrs. Vickers and Sons	55	44 15 3	171,309	0·062
26	Messrs. Park Bros. of Pittsburg . . .	56	46 8 10	102,966	0·108
27	Copper	..	89 16 8	296,622	0·072

In this credit was not taken for the value of the scrap copper. The price of steel was now much lower than when the trial was made in 1873; but if the value of the scrap copper was taken into account, the cost of putting in the steel box after a shorter mileage, and the extra cost caused by leaking, probably the balance would still be decidedly in favour of copper. It should be remembered that the copper for plates and stays, for both repairs and renewals of locomotives, did not exceed about one-twelfth of the whole material required, or about $\frac{1}{10}d.$ per mile. This was not a large amount to economise on, and therefore great care was necessary, lest the expenditure in labour required by the use of steel might not exceed the saving in the cost of material.

Mr. Fox. Mr. Samson Fox could not say much about the material used for locomotive fireboxes, but he believed his firm had supplied the material which had been used in portable-engine fireboxes. What he could say with regard to it would, however, principally apply to its use in making corrugated flues. His firm began to manufacture that particular class of flue at Leeds, with ordinary Yorkshire plate, built up in the usual way of making Yorkshire iron; but after a while the result was not successful, on account of the

lamination in the plates. That, he thought, was in part due to the corrugating of the surface. He considered the best thing that could be done would be to turn to a mild steel, and he tried every maker of steel for plates which would fairly compare with the Lowmoor boiler-plate, but at that time he could not find plates sufficiently ductile and soft for the purposes of welding. He might explain that in making the tube, it was first of all bent, and then welded, and the difficulty of finding steel plates that would weld safely, and afterwards stand corrugating, showed the necessity of having a very mild plate which would meet the other conditions required in the working of the firebox. Since that time his firm had made a large number of fireboxes, and the steel which they used bore an elongation of something like 30 per cent. in 10 inches, the tensile strength varying from 22 to 25½ tons per square inch. They had also found that the thinner the plates the better they seemed to last. There were now at least six or seven thousand of these tubes in marine and in land boilers. Some had been at work over four years, and there was no sign of the steel blistering; but the iron tubes first made, of which there were about one thousand in use, were showing signs of gradual shelling away. The steel so far showed no such sign, and he quite agreed with the Author of the Paper that iron gave trouble and that steel was successful. The steel contained a percentage of carbon, 0·13; manganese, 0·3; silicon, 0·035; sulphur and phosphorus about 0·04. That gave a material which welded freely, and as compared with iron, on welding it afforded a considerably stronger joint with the same system of operation. The best system of welding he had ever known was to use ordinary town-gas mixed with atmospheric air. In that way he had managed to bring the welded joint with that mild material up to very nearly the full strength of the plate, with a ductility of something like one-third of the ductility in the plate not welded. That was, in steel, with a tensile strength of 22 tons per square inch, a welded joint had a tensile strength of nearly 21 tons, and an elongation in 10 inches length of about 8½ per cent. That could not nearly be equalled with iron, taking the same class of iron as that used to make the tubes from. When coke was employed in welding the strength was about 14 tons to the square inch on 22-ton plate, with an elongation of a little over 6 per cent. His experience therefore was that the softer the steel the better it was both for the work that it had been put to and the various processes of manufacture, especially the welding of the joints. The weld was a scarf weld with a lap, taking the ½-inch plate, of about ¾ inch. The edges of Mr. Fox.

Mr. Fox. the plates were sheared. They were tacked together at each end of the tube with a lap, and the weld was commenced from the centre, working out towards the end. Having got to one end, the tube was turned round, and, starting again at the centre, the weld was carried out to the other end.

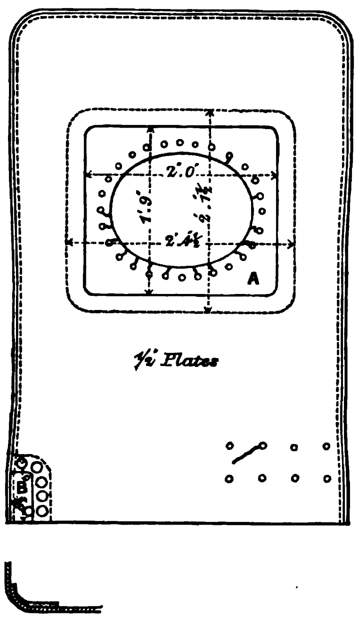
Sir Frederick Bramwell. Sir FREDERICK BRAMWELL asked to be allowed to add one word in continuation. Mr. McDonnell had spoken of the difficulty of keeping the tubes tight in the tube-plates. Sir Frederick Bramwell had already mentioned his visit to the Grand Trunk Railway, and he had before him a note he had made at Montreal, which was as follows: "Their tubes are iron. At the firebox end they have put outside of them a thimble of copper, cut off a copper tube. The expander sets the tube hard out against the copper, and the copper against the tube-plate. A finishing tool throws the projecting end of the tube over the copper, as sketched. They say, since they have used this plan, they have cured all their trouble about leaky tubes."

Mr. Park. Mr. J. C. PARK understood that the Author challenged the English practice with regard to fireboxes. Some ten years ago he was at Inchicore, and Mr. McDonnell, having heard some good reports of the steel, was induced to give an order for some American steel plates. Those plates came from a very eminent firm. He was led to believe that the firm had the largest experience, and that he was therefore getting the best article. The plates arrived, and they were tested as directed by the maker. Strips were cut off the ends of the plates, they were heated to a bright red, then dipped, put under a steam-hammer, and doubled up. No fault could be found with the plates, and it was hoped that they would perhaps be able to be used in place of copper for fireboxes. He did not remain at Inchicore long enough to see the boxes tried, but he came to the North London Railway in 1873, and on his arrival found that his predecessor, Mr. Adams, being anxious to try the experiment, had built six boxes of ½ inch steel plates, supplied by a firm in Sheffield. Mr. Park was agreeably surprised to find that the same trouble had been taken as at Inchicore to test the plates, and in the same way to ascertain that the plates were perfectly sound. He said, "That is very satisfactory, and no doubt it will lead to our being able to replace copper," because it was well known that the copper at that time was not the copper of twenty or thirty years ago. The boxes were put to work, and in a very short time he found that they were going to give trouble. In a few weeks the fireboxes had to be repaired by putting copper patches on them. The steel had the

Mr. Park.

appearance of being equal in every respect to the American steel. With one box a mileage of 135,000 had been obtained. The average of the six boxes was 85,000 miles, the lowest being 51,000 miles. In two and a half years the boxes were condemned, and arrangements were made to take them out. Figs. 6, 7, 8, and 9 represented four of these fireboxes where they had failed, and the mode in which they had been repaired. The Americans had never been successful with copper. He was six years in America as a locomotive engineer, and all the engines he had were provided

FIG. 6.

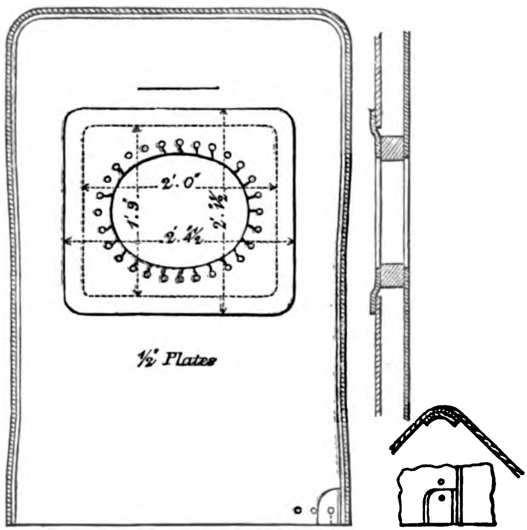


Steel Firebox. No. 34 Engine. Boiler tested 25th July, 1874. Commenced to run 2nd September, 1874. A copper patch put on 26th September, 1875; B ditto 20th December, 1875. One crack in tube-plate between the third and fourth rows of stays from bottom. Firebox taken out June 1877. Mileage, 84,309.

with iron boxes, but at that time wood was used as fuel, which was said to be very suitable for iron boxes. After he left America, however, the wood was exhausted, and coal was resorted to. The iron boxes then gave way, and copper ones were introduced. These were equally unsuccessful, and no doubt steel had been found to suit the purpose better. In England a different fuel was used, and he wished to give the mileage now being practically obtained with copper fireboxes. On the North London Railway, with a pressure

Mr. Park. of 160 lbs. to the square inch, and a mileage per passenger engine of 47,000 per annum, the copper boxes to which he referred had made an average mileage of 349,000, that being the average of the forty-eight that had been replaced within the last five or six years. The greatest mileage obtained was 559,000, during a period of nineteen years. That showed clearly enough that with the fuel used in England there had been no necessity, as in America, to use steel for fireboxes. He did not see that the Paper took credit for a greater mileage than he had stated. It was

FIG. 7.

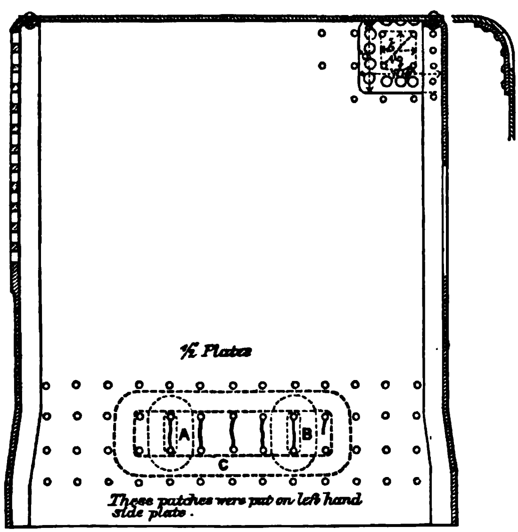


Steel Firebox. No. 38 Engine. Boiler tested 3rd July, 1874. Commenced to run 15th August, 1874. A steel patch put on in corner as shown, owing to a crack being discovered from bottom of plate to first rivet hole, 18th February, 1875. Mouthpiece cracked in the rivet-holes; the steel plate was cut away, and a copper patch put on, with copper studs, 13th April, 1875. There are nine cracks in tube-plate between the first, second, and third rows of stays from bottom. Right-hand side plate cracked between fourth and fifth rows of stays from bottom, and fourth row from tube-plate; patch put on to take nine stays, and studded with iron studs; patch renewed four times. Firebox taken out August 1877. Mileage, 88,214.

evident from all he had heard of the trials in this country that engineers had not been successful with steel. The Americans stated that that was because the plates used were ½-inch thick, and there might be a great deal of truth in that. A mistake might have been made with regard to the thickness, and he had been anxious to satisfy himself on that point. He had a large locomotive boiler made for stationary purposes, of $\frac{5}{16}$-inch steel; the box was 6 feet long, and the pressure was only 100 lbs. per square inch.

There was no blast, and altogether the working of the boiler was Mr. Park. favourable to thin plates, but in two and a half years the firebox of $\frac{5}{16}$-inch steel had to be replaced by one of copper. On the North London Railway it was reckoned that a locomotive engine earned about £5,000 a year, and if the firebox had to be taken out after it had run even 100,000 miles, the expenses would be considerably increased. That company had therefore adhered to copper. He had no doubt that an endeavour would be made in

Fig. 8.



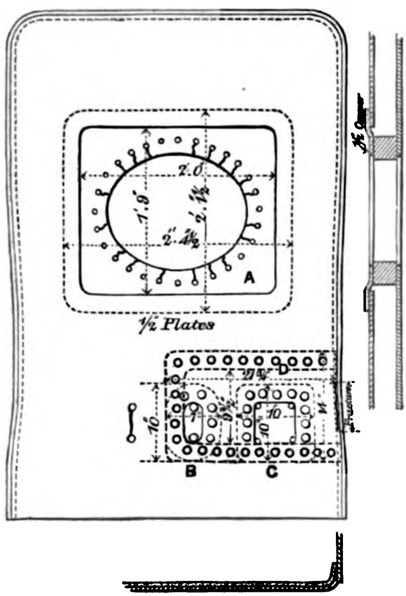
Steel Firebox. No. 39 Engine. Boiler tested 16th May, 1873. Commenced to run 29th May, 1873. Cracked in the stay-holes, a piece cut out, and a steel patch put on, with iron rivets, 17th July, 1873. Cracks were found in left-hand side plate, steel patches A and B were studded on; more cracks were found as shown, so A and B patches were taken off, and plate cut away and replaced with copper patch C. There are six cracks in right-hand side plate, between first, second, and third rows of stays from bottom. There are four cracks in tube-plate between first, second, and third rows of stays from bottom. There are eight cracks in back plate between first, second, third, and fourth rows of stays from bottom, and cracked very badly in rivet-holes round fire-hole. Firebox taken out May 1877. Mileage, 135,816.

England to get a steel that would take the place of copper, as the copper of to-day was not like the copper of twenty years ago, and did not yield the same mileage. He should be glad if the Paper induced steelmakers to take up the question, and supply steel which would stand the required work.

Mr. T. W. Worsdell said he had not had much experience during Mr. Worsdell. the last ten years with steel fireboxes, but he had been for seven years in America in connection with railways, and during that

Mr. Worsdell. time he had occasion to test pretty thoroughly the merits of soft steel for firebox purposes. That was in the early days of using steel, because, as Mr. Park had observed, there was a transition state from the iron fireboxes in the time of burning wood for fuel to the use of copper fireboxes when coal was introduced. When he undertook the charge of the repairs on the Pennsylvania Railroad he found that the copper fireboxes had worn so rapidly and become so thin between the stays that fractures were

FIG. 9.



Steel Firebox. No. 42 Engine. Boiler tested 23rd July, 1874. Commenced to run 27th August, 1874. The mouthpiece cracked in the rivet-holes; the steel plate was cut away, and a copper patch A put on, with copper studs, April 1875. B copper patch put on 19th October, 1875; C ditto, 6th November, 1875. The fracture in flange of front plate was 6 inches long. The flange and patches B and C were cut away, and copper patch D put on, with iron studs, 14th March, 1876. There are also thirteen cracks on bottom of tube-plate at second row of stays. Engine stopped for new firebox, 27th March, 1877. Mileage, 81,966.

frequent. After long consultation, iron was tried again and again, but either the iron was not of such good quality as had been supplied before, or the nature of the fuel was such that the iron would not stand its action. Mild steel was then suggested, and from the tests that were made it was thought much more pliable than any iron previously used, and it was accordingly made into a firebox of the description shown in

Mr. Worsdell. the drawing. It stood remarkably well, and there was not the same amount of leakage or the same amount of caulking about it that had been found necessary in the iron boxes. It was then tried still further, and he was so satisfied with the quality of the material that before he left he had put in between two hundred and fifty and three hundred steel fireboxes, and he did not remember a single failure due to the steel. One reason of this success was that the water was practically clean. He was convinced that the slightest deposit or accumulation upon the sides or roof of a steel firebox would soon make it yield. All along the road there was very good water except on one colliery line, or a branch that went through the collieries. One of the engines with a steel firebox was stationed on that line, and a report came that the firebox had failed; it was not by an explosion, but was simply a failure. He sent for the engine, and found that on the top of the firebox, just about the centre between the stays, a quantity of dirt had been deposited; it had got heated, and the steel had cupped down by breaking one or two of the roof stay-bolts, and the holes that had been left by the breaking of the stays had allowed the water to put the fire out, thus averting any further damage. That was due entirely to the accumulation of dirt, not one of the fireboxes had failed from the quality of the steel. At that time the maximum pressure was 130 lbs. to the square inch, but a higher pressure than that was now used. The thickness of the steel was $\frac{1}{4}$ inch, except the tube-plate, which was only $\frac{3}{8}$ inch thick. This was much too thin, but fears were entertained of greater thickness, having had the experience of iron boxes. If the steel could be $\frac{1}{8}$ inch thick, which was mechanically impracticable, he believed it would be still better, but $\frac{1}{4}$ inch was thin enough to get the screwed stays in. On coming to England when he had charge of the works at Crewe, under Mr. Webb, a trial of steel did not prove successful. The steel lasted for a time, but one or two of the boxes cracked a little, from the ring upwards. The others were then taken out. Only five boxes had been made, and that constituted his experience in connection with steel boxes in England. But he believed the English method of making steel boxes was not the correct one. According to the American mode every surface had a separate plate, but the English made a plate that went right over the whole surface of the box. At Crewe Mr. Webb wrapped it round the other way, but he did not think either was a safe practice for steel. There was a little variation in the condition of the steel in different parts of a large plate; one corner might be rather

Mr. Worsdell. different from another, according to his experience, and he thought that the smaller the plates the more chance there would be of the firebox standing. The Author had recommended English railway companies to adopt the American method of direct stays for fireboxes. He had come to this conclusion rather suddenly. Mr. Worsdell, having had some experience of both methods, preferred the old kind of staying, especially with a copper firebox. The direct stay might be all very well away from the tube-plate, but at the tube-plate end trouble was often experienced on account of the expansion of the boxes both upwards and through the tubes. Reference had been made to fixing tubes in the steel tube-plate. That was a source of the greatest trouble. It seemed as if the behaviour of the hard metals together, and the direct expansion of the comparatively thin iron tube, did not make a good joint in the firebox end, and the practice of a copper thimble outside the tube had been resorted to. He remembered a boiler, or what was left of it, with every tube drawn out, and each tube had had an outside thimble on. He did not, therefore, think that that practice, without some modification, was a very safe one to work upon. He knew that it had been adopted, but the tube required to be a very thick one, and turned over at the end, or he should be afraid of some such result. The water-tubes from the roof of the firebox to the lower part of the tube-plate were simply used for carrying a brick arch as a convenience; they were not there for generating steam. But he had known a case of water having got low in the boiler, where a jet of water must have rushed through the tube acting as a siphon. This cooled the firebox, otherwise the time spent in putting the fire out might have led to a disaster; so that that was accidentally a benefit. If steel for fireboxes was employed under the high pressures now used, and with the excessive wear occasioned by the amount of fuel consumed, the metal must be as thin as possible consistent with strength, so as to get the water as near the fire as possible, and the smaller the plates the better. Then there was another evil; the flanges or double thicknesses, as Mr. Thornycroft had said, began to show cracks from the rivet-hole upwards. He had found that a comparatively thick flange-plate, in one instance, was subject to cracks; he then turned it outwards, and had no trouble with it whatever. He did not think that bad fuel was detrimental to the steel firebox; he should think it was much more detrimental to a copper firebox, especially coal that had a good deal of sulphur in it. On the Pennsylvania Railroad some most execrable coal seemed to have no deleterious effect upon the fireboxes.

Of course the steel firebox was admirably adapted for anthracite coal as copper fireboxes were liable to melt down on the fire surfaces; they had to be made much thicker than steel ones. Mr. Worsdell.

Sir John Hawkshaw.

Sir JOHN HAWKSHAW, Past President, said his early experience of iron fireboxes and iron tubes dated from 1836, on the Manchester and Bolton Railway, on which he was then engaged. All the locomotives had fireboxes and tubes of the description he had mentioned, and they ran in the usual way until they ceased to be any longer available. The iron fireboxes caused considerable trouble in one respect, they were apt to blister; but by putting on a plate they were kept going. In the course of time, however, they were abandoned for copper fireboxes. He had been in the United States twice during the last four or five years, and finding that such a thing as a copper firebox was unknown there he naturally inquired into the reasons for the use of steel. He knew that steel had been used in England to some extent, and that locomotive engineers had ceased to use it because they said it did not answer. He stated those facts to the American engine-makers, and those who superintended their working, and they said: "We cannot understand why they did not answer, because here they answer perfectly; we should never think of using copper fireboxes, and we find the steel fireboxes answer our purpose extremely well." Returning to England, he stated the experience of American engineers to some of the locomotive managers, but they said: "That may be so; all we can say is that we have tried steel, and it does not do." The conclusion he had come to was that there must be some great difference either in the steel used in America and in England, or in the method of adapting it to locomotive fireboxes. Nothing could be more certain than that in the United States steel locomotive fireboxes answered perfectly, and nothing seemed better established in England than that steel fireboxes did not answer so well. He believed the difference arose from the fact he had mentioned. The Americans did several things better than Englishmen. For this purpose they made better steel, and he knew that they made better cast-iron. They ran cast-iron wheels at great velocity, while Englishmen had abandoned them on the ground that they were not safe. The Americans, however, made a cast-iron which was as superior to English cast-iron as steel was to common iron. With regard to fireboxes, he was certain that they made a steel firebox which was not open to the objections raised against them in England. So strong was that impression upon his mind that he had tried to persuade some of the companies with which he was connected to send the dimensions of one of their fireboxes to the United

Sir John Hawkshaw. States and get a firebox made there, in order that they might see how it worked. He was persuaded that the difference of practice arose, not from any incompatibility of material, but from the fact that it was manufactured differently; and probably also treated differently with regard to the thickness and its mode of arrangement.

Mr. Crampton. Mr. T. R. CRAMPTON did not think any allusion had been made to the power of conducting heat from the inside of the firebox to the water. The thinner the plate, particularly if made of iron or steel, the better. A 1-inch plate of iron would last a very short time, whereas copper would last a very long time if it were only ½-inch thick. He believed that was one reason why the thin plates were answering so well. With regard to the stays at the top, in 1849 he recommended Mr. Petiet, of the Northern Railway of France, to try them. They had been used in Belgium and various other parts of the continent, and of late years they had been tried in England. He impressed upon Mr. Petiet, at the time, to take care not to have the stays too close to the angles, and allow for a certain amount of elasticity at those points. Where that had not been done the stays had given a great deal of trouble. In 1845 he eliminated entirely every angle-iron in his boilers; be believed everybody did so now, but at the time he referred to, he established it as a system. He also made it a rule to make the diameter of the boiler the same as the outside of the firebox in order to give more space between the tubes and the side to allow free circulation. Those were matters which struck him as essential. With regard to the American practice, he thought there were one or two little points which ought not to be copied. He referred especially to the continued use of way-bars instead of a slide-gear direct on to the valve spindle. Again, the engines were highly ornamented, whereas English engineers liked to make them as simple and as plain as possible. With regard to the question of long fireboxes, in 1851 he put an engine in the Exhibition with a firebox 6 feet 9 inches long. He was always in favour of long ones, but they could not always be used. There were various circumstances in which it was not advisable to employ them, but they should be made as large as convenient. He noticed that the Americans were not extending the wearing surfaces to the same extent as was done in England. In some engines that he made for an express service in France in 1848, the bearings were 10 inches long, and 7 inches in diameter. He did not think there was a bearing so long as that now. The front axles were of the same length.

Mr. Joy. Mr. DAVID JOY little thought that the subject would have

attracted so much attention, and broadened out into so voluminous a discussion. During the last year he had visited the United States, when two questions were forced very strongly upon him; first, the use and quality of the cast-iron, and secondly, the quality of the steel, and the very thin fireboxes everywhere adopted. He was introduced to most of the locomotive superintendents, or master mechanics, as they were called, and everything was shown to him. Blue prints were given to him, and he was permitted to take dimensions wherever he desired to do so. He also visited a great many of the locomotive shops, and he saw the engines at Altoona referred to in the Paper. He could substantiate everything the Author had said with regard to fireboxes, although he could not admit all the Author's conclusions. He agreed with Sir John Hawkshaw, that if English locomotive superintendents would send for one of the American fireboxes to be tried in an English engine, the result would be very beneficial. He had also been at Scranton, where he saw many engines under repair, and he was much struck with the fact that the boxes appeared always to have failed 8 or 10 inches above the firebars, which were 6 or 7 feet long, and of the usual width, and the worn parts were cut out and patched with steel. In Mr. Fernie's list many engines had been represented as running over 400,000 miles without repair. He had often seen the Wootten engines on the Philadelphia and Reading Railroad, where he witnessed some admirable performances, both as regarded the high speeds attained and the heavy loads carried. He had with him a blue print of the boiler, furnished to him by the company. The firebox was 9 feet 6 inches long, and 8 feet wide, extending over the trailing wheels. The fuel burnt was anthracite coal in little bits about the size of the thumb. The cost of this coal was very little, and the engines were fitted to use it. The fire was about 6 or 8 inches thick, and it was so intensely white that one could hardly look at it; the flame rose probably 8 inches from the surface of the fuel. The engines had 21-inch cylinders, with a length of stroke of 22 inches, and he had seen them make more than three hundred and fifty-five revolutions per minute. They must therefore use an enormous amount of steam; and it appeared to be nearly all produced by the firebox, because they had very few tubes, only about 1,100 feet of heating surface. The duration of the fireboxes could not be accounted for on the assumption that they had little work to do; on the contrary, they were taxed most severely. The loads were very heavy. At Altoona, in one of the trains, he counted seventy-six wagons with double bogies; how

Mr. Joy.

Mr. Joy. many more there were he did not know, for he did not see the end of the train. Engines were being built there on what was called the consolidation type, apparently because two trains were consolidated into one and pulled with one engine. The diameter of the boiler at the smaller end was 51 inches, and at the larger end 57 inches. The firebox extended beyond each side of the boiler. Mr. Wootten told him that the traffic would not pay unless two trains were together and one driver made to run them both. The speed was only 12 miles an hour, and if the train happened to stick fast, the driver simply went to a siding and put half the train there, and then fetched the other half. He had received the same information from Mr. Buchanan, the chief engineer of the Grand Central Railway, who showed him reports of engines that had run over 90,000 miles without any repair. There was evidently a work being done by American engineers in the use of steel for fireboxes, and if the advantages as to saving in cost which the Author had pointed out really existed, it was worth while not to say that the system had been tried in England and would not answer, but to try it again, and to try it in the way that the Americans themselves had adopted.

Mr. Berkley. Mr. George Berkley said that the subject was one in which he felt interest, having been connected with the design, construction, and working of locomotives for forty-two years. Two important questions were raised in the Paper; first, why did locomotive fireboxes made of a material called "mild steel" endure longer in America than they did in England? And, secondly, would fireboxes, if made of that material, and used under the conditions in which fireboxes were used in England, be superior to the copper boxes which it was admitted were generally used in England? Before drawing attention to those questions he wished to notice three or four statements in the Paper which ought not to be allowed to pass without notice. The first he very reluctantly referred to, as he did not desire to comment upon the taste of the Author of the Paper. Mr. Fernie observed that "American engineers have long effected a great economy which English engineers have overlooked." He only noticed that statement, because, having been twice to America, and having had the privilege of meeting American engineers on the two lines referred to by the Author as well as others, he was sure that such a statement would not be approved by them. They were thorough good mechanics and intellectual men, and he believed they had the same high opinion of English engineers as the English engineers had of them. There was nothing in the Paper

itself which justified the statement. The Author had further stated that "many accidents" had arisen from galvanic action resulting from the use of copper and brass with iron plates. Of course he did not deny that galvanic action did take place; but he ventured to say that the statement was far too strong. From his own experience he should say that plates were much more injured by unmechanical arrangement, such as by attaching a thin plate to a solid mass, where, on contraction and expansion taking place, the plate would get gulleted rather than from any galvanic action. The next point was one of argument. The Author had described a "perfect firebox," which, he said, should have plates in the outer and inner boxes of the same material, because "the expansion and contraction should be equal, with similar changes of temperature." He thought it must be clear to most engineers that the cause of destruction would arise when the materials composing the inner and outer boxes were heated to the extreme temperature. The Author moreover said that the "inner boxes must be heated to a very much higher temperature than the outer;" consequently, speaking theoretically, he would have been correct if he had said that the inside and outside fireboxes must be necessarily of different materials, the material of the inside box expanding less with a given temperature than the outer. He did not wish, however, to dwell upon that as a matter of importance. The statement of the Author, that heavy roof-stays were common to all English boilers, he ventured to assert was not correct. Ten years ago he had his attention specially drawn to the staying of fireboxes; he went on some of the most important lines, where he found that the suspending bars between the inner boxes were then used, and he had used them ever since in a large number of engines. He had found no difficulty with them, because he had been careful to make the outer box of the proper form, and the curves large where the upright and horizontal plate of the inner box joined, so as to give freedom of action to that part of the box. One of the alleged causes why the so-called steel boxes endured longer in America than England, was that the plates were made thinner in America than in England. He did not doubt that the thinner a plate could be made for conveying heat from heated gases to evaporate water, the better it would be for that purpose; but the question was one of endurance—which firebox ran the most miles, and had the longest life? Several speakers had referred to the tube-plate of a firebox as being the weakest plate in it: it was the most cut up; it had the heat most directly impinging upon it. The tube-plate of the American firebox was Mr. Berkley.

Mr. Berkley. ½ inch thick, which was the thickest dimension known in any English firebox made of so-called mild steel. Too much importance ought not therefore to be attached to the question of thickness in comparing the endurance of the American boxes with that of the boxes which had been used in England. Another important point to which reference had been made, was the difference of material. Sir Frederick Bramwell had drawn attention to the question of so-called "mild steel" being in fact steel. Mild steel was said to be used in the American fireboxes, but on analysis it was found by Dr. Siemens to be composed of carbon 0·22, phosphorus 0·05, iron 99·72, and no other alloy. He had for many years been impressed with the importance of knowing where iron ceased to be iron, and where "steel" began to be steel, and during the last four or five years he had had constant experiments going on in his ordinary practice with that view. If a material had more than 0·2 or 0·3 of carbon, if it were made of impure materials originally, or if it contained any large proportion of manganese, or of silicium, or any large quantity of sulphur or phosphorus, and if this material were made hot and dipped into cold water, it would not bend; it would break. But if it were material with 0·2 per cent. of carbon, having a very small proportion of manganese and silicium in it, it would be found to be precisely like iron. He believed—though he did not assert it as a fact, because he had not sufficient proof of it —that the heating of that material and quenching it in cold water would somewhat toughen it. He was however certain from many experiments that it would bend to any desired extent after being heated to a red heat and quenched in cold water. If it were annealed, it would be by no means strengthened, but its constitution would not be materially, if at all altered. An analysis of the material made by Riley, and tests by Kirkaldy showed that it contained from 0·15 to 0·2 per cent. of carbon, and nearly 99·80 per cent. of iron, and that it bore a strain of from 24½ to 27½ tons per square inch, and stretched about 32 per cent. in 2 inches. He believed that one of the main differences between the boxes that had endured so long in America, and those which had not endured so long in England, was that the Americans had used homogeneous charcoal iron, a material having all the characteristics of iron; and that in England "mild steel" had been employed. No more distinct proof of that could be given than had been afforded by Mr. Thornycroft, who had handed in a piece of plate used by him in a firebox, and who said that when he struck the corner of it it broke off brittle. Sir Frederick Bramwell had given a graphic description of homogeneous iron: it was "as supple

as metallic leather," however the temperature was varied. The presumption was, therefore, that there had been a difference in the qualities of the material used in the American and English boxes. Another alleged reason for the greater endurance of American than of English boxes was that they were of a larger size, and that the material in them consequently did less work. When he was at the Philadelphia and Reading Railroad Locomotive Works, about two years ago, he saw these enormous fireboxes, and the head of the department explained to him that a very large fire-grate area was required to consume the small anthracite coal, which was procured for next to nothing. For a firegrate area of 72 square feet, as stated in the Paper, the boxes had to be of an immense size, and the cost would be very great if they were made in copper. There was, therefore, every reason for applying the "iron" or "steel" to save the first cost of such boxes. What was the result? Manifestly, drawing the same quantity of air through a very large firegrate, and acting in the very large cubic contents of the box, and upon a large surface, the work done by the material of which the box was formed would, on account of the lower temperature, and the larger surface to convey away that temperature, be less than in the small boxes with the small grate-area and strong draught of the English locomotive. A reason, therefore, of the great endurance of the American boxes was, that the work which the material had to accomplish had not been equal to the work done by English boxes. Some of the speakers had compared the heavy work in England endured by copper boxes with the smaller amount of work of the American fireboxes. Considering the conductivity and ductility (two words which he was sorry to say did not appear in the Paper) of the material, and all other circumstances, having regard to the statistics resulting from experience, it would be found that, if iron or steel boxes were made at all, English manufacturers should imitate the Americans in making them of the purest materials, and of large size. It would, in his opinion, even then remain doubtful if they would succeed in producing a cheaper, more enduring, and more economical firebox than the copper boxes which were used in England. Mr. Berkley.

Mr. FERNIE, in reply to Professor Kennedy, said he had no intention of doing any injustice to Mr. Kirkaldy, with whose testing-machine he was familiar, and whose efforts to establish a proper system of testing were worthy of all praise. But, if he erred in saying the American machine was the largest, he left the question of its highly original character to Sir Frederick Bramwell's description. As to testing-machines, and the testing of Mr. Fernie.

Mr. Fernie. materials being better understood and practised in America, a glance at a specification for an English locomotive would show that only five or six manufacturers could make locomotive boiler-plates, and that no test whatever was required from them; while the American specification quoted established:—First, a breaking strain; secondly, a percentage of elongation; thirdly, that all boiler plates must be stamped with this breaking strain; fourthly, that the maker's name must be stamped on the plate; fifthly, that a strip cut off the plate must be sent with it; sixthly came the action of the law, which fixed the liability on the maker, from damages which might occur from the use of the material at a lower strain than he had stamped it.

With respect to galvanic action, Mr. Berkley acknowledged its existence to some extent in English locomotive boilers; but his experience differed from the Author's, as Mr. Fernie found more boiler repairs needed from this than from any other cause. In fireboxes the greatest heat was where the hot fuel lay against the sides of the box, and it was here that the box wore out. At most only one-eighth of the tube-plate surface proper was exposed to the heat; the greater portion of the heat passed through the sides of the box into the water, and never reached the tubes. The admission of cold air from the fire-door also cooled down the air which impinged on the portion where the tubes were situated. English copper tube-plates were manufactured up to 1 inch thick, those of American steel up to $\frac{1}{2}$ inch thick. English copper fire-box sides were made up to $\frac{1}{2}$ inch thick, and American steel up to $\frac{1}{4}$ inch thick. The mileage of the tube-plates and fireboxes of both were known; and he could not admit what would follow from Mr. Berkley's argument, that ten or twelve years' successful use of thin steel in America was of no importance, compared to a few unsuccessful trials of thick steel in England. He did not think homogeneous charcoal iron was known in America. He believed as good steel was made in England as in America, but that the application was not so well understood. Mr. Worsdell, for instance, had put in hundreds of steel fireboxes in America, but was not successful with one such firebox in England.

As to the contention that the American fireboxes were made of steel to save in first cost, inasmuch as from their large size they would be very expensive if made of copper, surely the fact of a weaker draught and lighter work done by the large firebox would be a recommendation, as by it there would be less back pressure on the piston, and less cutting away of the fireboxes and tubes. But how did Mr. Berkley get these results? He cited the abnormal

boxes of the Philadelphia and Reading Railroad, which were constructed to burn the dust and rubbish which accumulated round the pit head of collieries, instead of taking the ordinary boxes of the Pennsylvania Railroad. Comparing a 17½-inch cylinder English engine, having 16½ feet of grate surface, with a 21-inch cylinder American engine, the latter should have 24 square feet of grate surface. But the Pennsylvania engines of that size had 23 square feet, while the particular form of firebox, tapering sides, and sloping roof, much diminished the surface for the heat to act upon. In respect also to the longevity of the American fireboxes, one box had run 505,890 miles, and four boxes an average of 454,439 miles, and, while English boxes had run over 500,000 miles, this was not a usual circumstance. In 1877 Mr. Stirling said "A copper firebox lasted from three to five years," and Mr. Kirtley, "Goods engines run 74,403 miles, and passenger engines 161,334 miles."[1] These two authorities would only give 100,000 miles as an average, and if so, the American boxes were doing twice the duty of the English at one-sixth the cost. Mr. Fernie.

American engineers had effected greater economy than the British in the manufacture of locomotive engines in several particulars:—In the matter of cast-iron wheels instead of wrought-iron; in entirely dispensing with crank-axles; in having steel fireboxes and boilers, and iron tubes, instead of copper boxes and brass tubes; in having much lighter frames; in being able, from the above reasons, to get a much more powerful engine with a lighter weight; and in using, relatively speaking, much cheaper materials. The latter point would, perhaps, require a little explanation. About twenty-five years ago, Mr. Krupp gave the world steel tires, which effected the greatest economy in railway working. These tires were made of crucible steel, and to this day English engineers specified crucible steel tires. Now, the Americans adopted steel tires at the same time, and seeing the great economy resulting from their use, they said, "let us extend the use of this valuable material," and hence their steel fireboxes were first made of crucible steel. But not satisfied with the price, they tried how to cheapen it by the Siemens-Martin process, and tires, axles, boilers and fireboxes were now made of this cheaper material, while on English railways, with perhaps one exception, no advance had been made upon what Mr. Krupp did twenty-five years ago. He,

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[1] Minutes of Proceedings Inst. C.E., vol. xlviii., pp. 59 and 63.

Mr. Fernie. as well as Mr. Berkley, had had a long and varied experience in locomotive work; and it was his opinion that the American locomotive could be built at from 30 per cent. cheaper than the English engines; that it was a much more reliable and economical machine, better adapted for colonial work, and that it was able to do more work than the English engine. He considered the improvements in welding steel boiler-plates by the process described by Mr. S. Fox as of the very highest importance, and, so far as he was aware, nothing so successful had been done in this line in America. In the thick-edged boiler-plates, invented by Mr. Alton and himself, of which they had made some boilers with welded longitudinal joints, they could not get more than 50 per cent. strength out of their welded joint, and the plates were of Lowmoor iron. He therefore hailed this step of Mr. Fox as a great advance, showing that steel was the better material.

Correspondence.

Mr. Banderali. Mr. D. BANDERALI, Locomotive Engineer of the Northern Railway of France, stated that the trials which had been made in France, and especially on his line, of steel as a material for locomotive fireboxes, had been absolutely unfavourable, and the company with which he was connected confined themselves exclusively to the use of copper, which gave great satisfaction. He was far from denying the advantages which the Americans seemed to have derived from mild steel, nevertheless the French engineers were at the present time utterly opposed to it. On the Northern Railway of France brass tubes with copper ends next the firebox tube-plate were employed.

Mr. Ely. Mr. T. N. ELY, General Superintendent of Motive Power of the Pennsylvania Railroad, said that the boilers and fireboxes of the locomotives of that company were now made entirely of mild steel, and that little or no trouble was experienced from cracks. In the long anthracite boxes some annoyance was at first experienced from this source, due to the washers not being careful to have the boilers thoroughly cooled before washing out; but since the use of the injector had been adopted to throw water for washing purposes, cracks seldom occurred.

Mr. O'Neale Neale. Mr. D. H. O'NEALE NEALE had found remarkably unequal results on examining Appendix I., giving the age and mileage of ninety-

two steel fireboxes that had worn out on the Pennsylvania Railroad. Mr. O'Neale Neale.

		Miles.		Miles.
1 had run over	. . . .	500,000		
4 „ between	. . . . . .	400,000	and	500,000
10 „ „	. . . . . .	300,000	„	400,000
38 „ „	. . . . . .	200,000	„	300,000
28 „ „	. . . . . .	150,000	„	200,000
9 „ „	. . . . . .	100,000	„	150,000
2 „ under	. . . . . .	100,000		

The average mileage being about 220,000, it would be seen that over 50 per cent. of the total number of engines gave results widely differing from the average. The age of the fireboxes when removed was even more anomalous.

	Years.		Years.
1 had run for about . .	16	11 had run for about . .	9
– „ „ . .	15	22 „ „ . .	8
– „ „ . .	14	22 „ „ . .	7
4 „ „ . .	13	8 „ „ . .	6
3 „ „ . .	12	6 „ „ . .	5
6 „ „ . .	11	2 „ „ . .	4
6 „ „ . .	10	1 „ „ . .	3

These figures would seem to show not only that the average life of a steel firebox was somewhat shorter than that of a copper firebox, but it was far more uncertain; and, as wear and tear should have fairly equal results under similar conditions, it would appear that many of these fireboxes failed suddenly and unexpectedly. A copper box was certainly free from this objection, the progress of deterioration was gradual, and could be watched and checked without any unforeseen stoppage of the engine, which was always inconvenient and costly.

The repairs of copper fireboxes generally arose either from the stay-heads and plates being burnt thin where the heat was greatest, about 18 inches from the bars; or from the tube-plate being cracked and bulged, chiefly through the longitudinal expansion of the tubes being greater than that of the boiler barrel. Steel stays and plates should not stand the action of the fire as well as copper, which was a better conductor, and in many old boxes hardly thicker, ¼ inch being generally considered the limit of safety.

It was obvious, therefore, that the superiority of the steel firebox must lie, if anywhere, in the tube-plate. Doubtless many copper fireboxes were over-stayed, and made so rigid that expansion was impossible. The Author once saw six old fireboxes of the same build being broken up on the Great Eastern Railway. In

Mr. O'Neale Neale. two of them the outer vertical rows of stays in the lower part of the tube-plate had evidently been fractured for some years, and there was an entire absence of grooving near the vertical joints between the saddle-plates and the sides of the firebox-casing, though this grooving was strongly marked in the remaining four boxes where the stays were unbroken. It was thus evident that the expansion of the copper rigidly stayed to the iron box caused a constant flexure of the latter, which, being concentrated at a weak point—the edge of a joint—furrowing as usual ensued. This could be prevented by keeping the stays some distance from the seams, when the expansion was absorbed by a bending of the corners. This remedy, however, was insufficient to deal with the difference in expansion between a brass tube and a boiler-barrel, each about 12 feet long; and, as far as his observations had gone, copper tube-plates under these conditions would crack, no matter what method of staying were adopted. When, however, either raised fireboxes, or shorter tubes, or iron tubes were used, it would be found that the tube-plates gave far less trouble, it being, however, in all cases essential that the tube-holes be kept clear of the flanges of the tube-plate.

The copper firebox was the one part of the locomotive engine that had been neither cheapened nor made more durable within the last fifteen years, and the advent of a lighter and less costly firebox would be welcome; but in this country steel, notwithstanding repeated trials, was considered an unsuitable material, and the Paper hardly gave sufficient information as to its general success in America to warrant further extended trials here.

Mr. Sandberg. Mr. C. P. Sandberg observed that the constant heating and cooling to which the fireboxes of locomotives were exposed, and the expansion and contraction of the metal caused thereby, were in favour of copper as the material for their construction, copper being much the more ductile metal and less liable to crack. Iron plates made from piles, although inferior to steel in solidity, had the advantage in not snapping, being formed of layers; on the other hand, these layers gave rise to blisters. Inasmuch as ductility was essential in the material for fireboxes, Bessemer steel was not so suitable as steel made by the Siemens process, the hardness of which could be tested and regulated in the furnace; but for fireboxes the purest raw material was essential. With respect to the manufacture of steel in America, it had been an axiom of the late Mr. A. L. Holley, M. Inst. C.E., and his views were supported by those of Professor R. Akerman of Stockholm, that besides the mode of manufacture, the choice of pure material

was the base of success. Where scrap-iron of absolute purity could not be obtained in sufficient quantity, Catalan blooms, almost free from phosphorus, were used, and, to secure ductility, every plate was bent and doubled up cold under the steam-hammer. The manipulation of steel ingots, not by hammering but by rolling in a Lauth mill, was also well adapted to secure ductility; and he had seen the same sort of mill used for rolling copper plates at Cwmavon Works, in Wales, many years ago. Mr. Sandberg considered the Pennsylvania Railroad Company inconsistent in their specification for firebox plates, seeing that they required mechanical tests only, whereas in their specifications for steel rails they insisted upon a definite chemical composition. He thought the combined mechanical and chemical test advisable for steel rails, but absolutely essential for steel fireboxes. He cordially approved of the advantages afforded by the testing-machine at the Watertown Arsenal, and of the American aim of testing the strength of structures rather than of the material of which they were to be composed, inasmuch as in structures of hard steel especially the strength frequently diminished in manipulating the material. In conclusion, he thought that steel had not been adopted for locomotive fireboxes in England for a commercial reason. Here engineers sought to obtain material of the greatest durability, so that the locomotive engines should be constantly at work with a minimum of repairs, the cost of material being a secondary consideration, and this was undoubtedly obtained by the use of copper. He felt confident that if the demand were to arise, English manufacturers would produce a quality of steel suitable for fireboxes. Mr. Sandberg.

Mr. C. Weston Smith observed, with regard to the class of steel best suited for locomotive boilers and fireboxes, he could hardly agree with the test-limits given by the Author. His opinion, based on the results of some thousands of mechanical, and no few chemical tests, experimental and otherwise, made from various tempers of Siemens steel during the past six or seven years, was that the quality having the greatest heat-imparting capacity was that capable of bearing an ultimate strain of from 25 to 29 tons per square inch, the highest pitch of ductility being attainable with the lesser limit. He would follow up the oft-repeated suggestion that some definite elongation-space should be fixed, as at present no favourable comparisons could be made, owing to the varieties of extension spaces in vogue. In the case of the limits given by the Author—25 to 30 per cent. in 2 inches—the same percentages shown in 8 or 10 inches would be by far the most Mr. Smith.

Mr. Smith. severe tests, and more in accordance with the tensile limits recorded. The direct rolling of the plates, as mentioned in the Paper, was a step in the right direction, also the reduction to a minimum of manual labour at the rolls. The substitution of steel for iron tubes would, he thought, be an improvement, the same plea as to galvanic action being set up, causing corrosion, &c., holding good with iron and steel as with copper and brass. He did not see any reason why, with the quality of steel just mentioned, the manufacture of locomotive boilers and fireboxes of that material should not become as general in this country as that of marine and other kinds, on the score, especially, of durability and economy.

Mr. Webb. Mr. F. W. Webb had not found steel for internal fireboxes of the rectangular form a success. To enable them to stand, they must be thin, and that meant a short life; and, however soft the plates were in the first instance, they appeared to harden with use.

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6 February, 1883.

JAMES BRUNLEES, F.R.S.E., President, in the Chair.

The following Associate Members have been transferred by the Council to the Class of

Members.

Joseph Bourne.
Clement Dunscombe.
John Ward Girdlestone.
Charles Horsley.

The following Candidates have been admitted as

Students.

Henry Charles Clifford.
Arthur Mansford Dalton.
Richard Bacon Eggar.
William Fairley.
Philip Joseph Holloway.
William John Jakeman.
Dawson Kitchingman.
William Jameson Layton.
Charles Tallent Spencer.
Rennie Charles Augustus Twyford.
Henry Seddon Wildeblood.
Walter Gunnell Wood.

The Candidates balloted for and duly elected were as

Members.

Baboo Khetter Nauth Chatterjee.
Charles Style Cochrane.
Francis Roubiliac Conder.
William McDougall Courtney.
John Middlemiss Luff.
Daniel Francis Martin.
James Otway, B.A.
Henry Wansborough Stevens.

Associate Members.

George Thomas Allen.
Alexander Barker Bassett.
Hugh William Stonehewer Bird.
Edward Herbert Blackburn, Stud. Inst. C.E.
George Frederick Blackmore, Stud. Inst. C.E.
Palmer Augustus Bourke.
John Buchan.
Jean Louis Napoleon Coste, Stud. Inst. C.E.
Joseph Prendergast Coy, Stud. Inst. C.E.
George Edward Wilson Cruttwell.
John Arthur Dockray, Stud. Inst. C.E.
John Thomas Eayrs.
Angelo Emanuel Edwards.
Richard Harris.
Thomas Musgrave Heaphy.
Horace Hey.
George Hill-Day, Stud. Inst. C.E.
Arthur Holt.
Percy William Monckton Holt, Stud. Inst. C.E.
Charles Cressy Horsley, Stud. Inst. C.E.
Harry Howell.
Andrew Johnston, Jun.
Hon. Cecil Johnstone.
Henry Miller.
Hugh Mitchell.
John Storan Moloney.
Edmund Legh Morris.
John Murray.
Oliver Stainton Pilkington, Stud. Inst. C.E.
Mervyn James Butler Pratt, M.A., Stud. Inst. C.E.
Lancelot George Prickett, Stud. Inst. C.E.
Herbert Gurney Sheppard.
Maurice Solomon.
Thomas Stewart, Stud. Inst. C.E.
Charles Stronge, Stud. Inst. C.E.
Alfred Weeks Szlumper, Stud. Inst. C.E.
Cecil Taylor.
John Augustus Thompson, Stud. Inst. C.E.
John Alexander Low Waddell.
Theodore Charles Troubridge Walrond, Stud. Inst. C.E.
Henry Deane Walsh, B.A.
George Robert Welby Wheeler.
Joseph Edward Willcox, Stud. Inst. C.E.
Arthur Prescott Wood.

Associates.

William Heron Coombs, *Lieut.* R.N.
Henry Dacres Olivier, *Lieut.* R.E.
George Robinson, *Retired Commander* R.N.

The discussion upon the Paper "Mild Steel for the Fireboxes of Locomotives in the U.S.A," by Mr. J. Fernie, occupied the evening.

13 February, 1883.

Sir J. W. BAZALGETTE, C.B., Vice-President, in the Chair.

(*Paper No. 1878.*)

"The Design and Construction of Repairing Slipways for Ships."[1]

By THOMAS BELL LIGHTFOOT, M. Inst. C.E., and JOHN THOMPSON.

THE history of slipways, like that of all modern mechanical appliances, is one of evolution, and dates back to a period prior to the present era.

Taking advantage of a conveniently sloping gravelly or sandy shore, the method of beaching was no doubt practised in very early times by the ancient Egyptians, in order to effect repairs to their vessels, which even then were constructed of sawn planks, and had sails as well as oars. Later, at ancient Carthage, the war galleys were drawn up a sloping shore on timber ways or slips, and this, the most primitive form involving the use of any artificial contrivance, has by gradual transition been developed into the modern slipway, with its powerful hydraulic hauling-apparatus capable of dealing with the largest and heaviest vessels.

Without considering the various stages of development, it may be stated that the earliest slipway, of the type proposed to be treated of in this Paper, was introduced in the year 1819 by the late Mr. Morton, of Leith. It consisted of ways, which were generally longitudinal balks of timber, carrying cast-iron rails, laid at any convenient inclination on a foundation of rough stones, of a cradle on rollers with adjustable sliding bilge-blocks, upon which the vessel was placed and drawn up, and of hauling gear, at first actuated by hand, and later by steam or hydraulic power. Since then the improvements introduced have been entirely in the details of the apparatus, which, from being at first merely required to deal with the light wooden ships in use at the commencement

[1] The discussion upon this Paper occupied portions of two evenings.

of the present century, is now constructed for speedily withdrawing from the water the largest existing iron vessels.

A general plan and side elevation of a modern slipway for vessels up to about 300 feet in length, and 2,500 tons gross weight, are shown in Plate 5, Figs. 1 and 2. Such a slipway consists: first, of a foundation, the nature of which must, of course, be specially decided by the engineer for each particular situation; secondly, of longitudinal timbers on cross-sleepers carrying cast-iron rails (Plate 5, Figs. 3 to 7); thirdly, of a cradle provided with cast-iron rollers and sliding bilge-blocks for receiving the vessel; and fourthly, of the hauling machinery. The modes of construction of the foundations, ways and cradle, present little variation in slipways of different systems; but the hauling gear, though now generally actuated by water-pressure, is subject to variation according to the ideas of the manufacturer or designer.

It is proposed to consider briefly each of the four sections, and to describe the operation of working when it is required to take on a vessel for repairs.

After deciding upon the construction of a slipway, it first devolves upon the engineer to fix the inclination of the ways. This can generally be at once determined by a consideration of the amount and value of land at his disposal, by the depth of water it is necessary to provide over the cradle when at its lowest position, and sometimes by the natural slope of the ground. As a rule, gradients of from 1 in 15 to 1 in 22 have been adopted; but these by no means form a limit, as it is obvious that no special engineering difficulties attend the introduction of either a greater or less inclination. The most suitable description of foundation can only be arrived at after a careful survey of the ground, and it is of course best to take borings from top to bottom of the site. In some cases no further preparation than mere surface-dressing will be wanted, while in others it will be necessary to provide a bed of concrete or stone filling, or even to drive piles under the ways. As a rule, however, the foundation of a slipway is not a difficult or an expensive matter, as the weight of the vessel and cradle is spread over such a large area that the pressure per unit of surface is very little, not more indeed than from 7 to 8 tons per lineal foot of way. The Authors are of opinion that piling should never be resorted to except in cases where it is absolutely necessary, and even then only with great caution, unless the whole length of way is to be piled. When part of the ways are supported on natural ground and part on piles, a difficulty is very likely to arise at the junction, for, the ground being more or less yielding, the cradle,

drawn on to the more rigid piled-portion, is subjected to excessive local stresses, which would probably cause breakage of rollers, carriage or rails. What is to be aimed at is to have a uniform support for the ways throughout their entire length, and where the formation of the ground varies, this uniformity must be obtained by excavation and filling-in with suitable materials.

The longitudinal timbers or rail-bearers, disposed as in Plate 5, Figs. 3, 4 and 5, are supported by transverse sleepers 12 inches wide by 6 inches deep, placed close together. The cluster of timbers forming the centre-ways for a slipway, such as is now being considered, consists of three balks of Memel or sawn pitch-pine, each 13 inches square, all with scarfed and keyed joints, while the outer bearers, which are spaced about 25 feet apart from centre to centre, having but little weight to carry and distribute, are composed of single timbers also 13 inches square. After the first starting of a slipway slight settlements are sure to take place, but are easily compensated by wedging up the rail-bearers where required.

In order to obtain sufficient depth of water to permit vessels of the desired capacity to float over the cradle when run down, it is necessary to carry the ways a considerable distance into the water. For this reason, except in situations where from the great range of tide the construction of the lower portion can be entirely effected at low water, the employment of divers is necessary. To avoid this increased expense various proposals for shortening the slip have from time to time been made and carried out. The simplest and usual plan is to make the cradle telescopic, that is, in several divisions attached to each other by sliding lengthening-bars which permit the various sections to close up when the cradle is run down for taking on a vessel, and to open out as soon as the hauling-up commences. This arrangement is successfully adopted in several slipways worked on the Authors' system. Another plan, applicable in situations where there is sufficient range of tide, is to enclose the upper part of the slip within water-tight walls, provided at the bottom with gates, which being shut at low-tide exclude the water. This method was selected in the case of a slipway on the River Tees, also worked on the Authors' system, but the gates are not now used. When it is necessary to employ the aid of divers in constructing the lower submerged portion of a slipway the work is generally carried out in the following manner. The rail-bearers are first of all framed together on land, on a continuous platform of transverse sleepers (Plate 5, Figs. 3 and 4). The rails are then fixed, and, the land end of the bearers being properly scarfed to join the last

length laid from shore, the platform is floated out as nearly as possible over the position it is intended to occupy, the bed having been previously prepared by dredging, or by sinking and levelling up a sufficient quantity of stones, or by both. Guide-piles being driven, the platform is loaded with stones and sunk, after which the ends are keyed to the shore timbers, and the stone-weights, which are to be permanently left, adjusted, sights being taken from time to time from the top of the way to check the correctness of the work during sinking, and before it is finally left.

The rails already alluded to (Plate 5, Figs. 5 and 6) are of cast iron. The outer ones are single, about 5 inches deep and 5 inches wide, while those at the centre are double, of nearly the same sectional dimensions, and connected to each other by a plate on which is cast a strong rack of about 6 inches pitch, for receiving the holding pawls on the cradle. These pawls are introduced to prevent the cradle running down the way in the event of an accident happening to the hauling gear. In the Authors' system wings are cast on each side of the centre rail, to support and guide the hauling links, which extend nearly to the bottom of the ways. The rails must be accurately cast, and are laid on the timbers with an intervening layer of felt to ensure a good bed. The joints must be carefully made, and throughout this work it is absolutely essential to avoid all inaccuracies, as they would be certain to lead to breakages of rollers, carriages or rails, which, though not endangering the safety of the vessel, would seriously interfere with the efficient and economical working of the plant.

The cradle, Plate 5, Figs. 1, 2, 5, 6 and 7, is a structure of timber, generally American oak, so constructed as to receive and maintain the vessel in very nearly the same trim as that in which it floats. It consists of a strong tapered centre rib, about 280 to 300 feet long, of several balks securely bolted and fastened together, forming the rest for the keel blocks, and of two lighter side ribs corresponding in position with the side ways. From the centre rib to each of the sides stretch transverse pieces of iron or of wood, carrying sliding bilge-blocks, worked by ropes-and-gear from the deck of the vessel or from jetties. These jetties as a rule, extend either on one side or both sides of the ways (Plate 5, Figs. 1 and 2), for the purpose of affording convenience in placing the vessels on the cradle, and for superintending the whole operation, which it is important to complete without loss of time. The sliding bilge-blocks are trimmed with supplementary loose blocks, shaped to suit the size and description of vessel to be hauled up. The cradle-ribs are carried on numerous cast-iron rollers, in cast-iron carriages

(Plate 5, Figs. 5, 6 and 7), those at the centre being placed as close together as possible, while those for the sides, where the pressure is small, may be spaced some distance apart. About ten of the centre-carriages are formed to receive the cradle-holding pawls, previously referred to. It is also usual to provide two or three short independent cradles or ekes, which may be attached to the top of the main cradle, according as the vessel to be repaired is long or short. The other adjuncts of the cradle are—wrought-iron ploughs at the aft end of each rib for removing silt or mud, or any other obstruction that may accumulate on the lower portions of the rails; hinged iron rods for guiding the keel of the vessel properly on to the centre of the cradle, one pair of rods being placed at the top for the bow, and a second pair at the bottom for the stern; besides sundry gear for working the bilge-blocks, and for lifting and lowering the pawls.

The hauling machinery usually consists of one or more direct-acting hydraulic cylinders placed at the top. Water is forced into the cylinder, and the motion transmitted from the rams to the cradle by means of strong forged-iron rods or chains. In some cases engines with gearing are used, especially if the slip be for small vessels.

The mode of working is as follows:—The general size and description of vessel to be taken on having been ascertained, the bilge-blocks on the cradle are trimmed to fit the ship as nearly as possible, and the guide-rods and other fittings looked to and put in proper position. The cradle is then run down into the water by its own weight, assisted, if necessary, by a down hauling chain worked by an independent apparatus at the top, arranged also for quickly drawing up the empty cradle after launching a vessel. The extreme end of the cradle may project 30 to 50 feet over the end of the rails, the main ribs being made strong enough for this purpose. The vessel is now floated into position as accurately as possible, being guided by hawsers manipulated from the jetty or shore, and also by the fore-guides fixed at the front of the cradle, which are drawn up into a vertical position by ropes afterwards secured on the vessel. The hauling-up then commences, the ship all the time settling on the keel-blocks placed on the centre rib, and being guided at the stern by the aft guides. At the proper time the sliding bilge-blocks are drawn in by ropes previously taken up to the jetties or on board the vessel, and so the operation proceeds until finally the ship is drawn up out of the water, safely seated on the cradle, and supported uniformly over the whole length of keel as well as by the bilge-blocks on each side.

In launching, the reverse process takes place. The vessel is lowered by the machinery to within a convenient distance of the water. The cradle is then disconnected from the links and, the holding pawls being raised, is left supported entirely on one special single pawl or dagger at the top. The dagger is now knocked out by a blow from a hammer, and the cradle with its burden runs down the way till it reaches the water, and the vessel floats off. The empty cradle is drawn up by the supplementary hauling chain, and after trimming is ready to take on another ship.

Having now generally described the construction and working of a slipway, it is intended to consider some improvements lately introduced in the cradles, and to enter more fully into the various systems of hauling gear.

A method by which a single slipway can be made available for repairing two or more vessels at one time is of obvious importance, the single set of expensive hauling-up machinery, and the single cradle doing double or treble work, and so reducing the amount of capital invested, in proportion to the value of the repairs effected. This improvement, which has been introduced of late years, is called relieving, and is accomplished in the following manner:—

The transverse arms of the cradle connecting together the centre and side ribs, and carrying the sliding bilge-blocks, instead of being permanently fixed, are hinged at their outer ends to the side ribs, and are thus capable of being swung round parallel with the side ribs, upon which they rest when in this position. After the vessel to be relieved has been hauled up, strong balks of timber are placed between each pair of transverse arms, to act as bilge-blocks, capable collectively of eventually carrying the whole weight of the vessel. Commencing at the top, and simultaneously on each side, these new blocks are tightly wedged against the bilge of the vessel, the weight being in this manner relieved from each old bilge-block and taken by the new ones resting on the ground. All the old blocks are thus relieved, and slid out on the arms, the vessel resting on the new blocks and on the keel blocks on the cradle. These latter are now relieved by placing under the keel, at proper intervals, hydraulic presses connected with the pumps. Water under pressure being introduced into these presses, the vessel is raised just sufficient to permit the keel-blocks to be knocked out, after which on exhausting the water from the presses the ship sinks back and is entirely carried by the new blocks supported on the ground. The cradle is now clear and relieved from the vessel, and so soon as the hinged transverse arms are swung round into a longitudinal

position, can be moved down the ways, and is ready to be used for another vessel. In this manner lengthening can be readily carried out by cutting the vessel before taking it off the cradle, and relieving each part separately, the second part being moved down the way upon the cradle for a distance corresponding with the additional length required. As a matter of arrangement, it is, of course, necessary to place those vessels requiring the longest time for repairs at the upper part of the ways.

A new method of relieving (Thompson and Cooper's patent) has just been brought out by one of the Authors, and Mr. George Cooper, the late manager of the Penarth Slipway Company, Limited. It is shown in Plate 6, Figs. 8 to 11, and may be thus described:— Instead of employing one cradle, two are used, constructed in such a manner that a vessel having been hauled up to a certain point upon the main cradle, can be transferred to the auxiliary one, the main cradle being thereby set free to receive a second vessel. With this object in view the main rails of the slipway are constructed in the ordinary manner, and at the ordinary inclination, but of such additional length as may be required for the working of the auxiliary cradle. Alongside the upper portion of the main rails, and parallel with them, is placed a second set of ways upon which the auxiliary cradle travels. The slope of these rails is greater than that of the main ways, in order that when a vessel has been hauled up until it is over the auxiliary cradle, and new bilge-blocks have been fitted, the heaving up of the two cradles simultaneously may cause the vessel to be gradually lifted up by the auxiliary cradle from the increased inclination of its rails, so leaving the main cradle free to be lowered down the ways for receiving a second vessel, after the transverse arms have been swung round into a longitudinal position.

When the ship is to be launched, the main cradle, with its arms swung round and resting on the side ribs, is hauled up under the vessel, the arms are then put into position and the bilge-blocks run in, and the main and auxiliary cradles simultaneously lowered down the ways. The greater slope of the rails of the auxiliary cradle causes the vessel gradually to approach and seat itself on the resting blocks of the main cradle, and the bilge-blocks on the auxiliary cradle being removed, the vessel, now supported entirely by the main cradle, is run down the ways and launched.

The form of hydraulic hauling-gear so successfully introduced by the late Mr. Morton has had very extended application. It consists of a single direct-acting hydraulic cylinder with one ram

having about 10 feet length of stroke. On the outer end of the ram is a crosshead, and to this crosshead are attached two wrought-iron bars, one bar passing on each side of the cylinder. These two bars are connected at their lower extremities to a second crosshead, to which wrought-iron links for hauling up the cradle are secured. Plate 3, Figs. 12 to 14 show the general arrangement of this gear. In hauling up a vessel, after the ram has made one outward stroke, it is necessary to pause to disconnect and remove one of the links, which are made in lengths to suit the stroke of ram. This having been accomplished with the assistance of a small hand-crane, the ram is run back by a constantly acting weight and a new attachment made between the links. The ram then makes another forward stroke, drawing up the cradle another 10 feet, and the process of disconnection and connection is repeated until the vessel is hauled up a sufficient distance. With the heaviest vessels two lines of links are generally used, as shown in Plate 7, Fig. 14, and two links have therefore to be disconnected and connected at each stroke. The great objection to this system is the delay and labour incurred by the removal of the links, and it was to obviate this that the Authors designed the form of hydraulic gear shown in Plate 7, Figs. 15 and 16, which has been successfully at work in several slipways since the year 1874. In place of working the press directly from the pumps, a small accumulator is introduced for the purpose of accumulating water pumped during the act of reversing the rams, and as the water-pressure is constant a set of treble-powered cylinders, or a cylinder with two or more concentric rams, is used for giving the variable power. A crosshead is actuated by the rams, and is connected to a second tail-crosshead by two forged bars. From this tail-crosshead a double set of links, shown in Plate 5, Figs. 5 and 6, extends nearly to the end of the ways, resting upon the wings cast on the centre rails, and being guided thereby. To the top crosshead is attached a ram working in a cylinder always open to the water-pressure. The action is as follows:—

Water from the accumulator having been admitted to one or more of the main hauling-rams, according to the weight and position of the vessel on the ways, the crosshead is pushed up, forcing the ram into the returning cylinder and drawing up the links. On reversing the valve-lever, the pressure is shut off and the main cylinders opened to exhaust, so that the constant-pressure ram reverses the stroke, forcing in the main rams and pushing down the links to the position from which they started. A definite upward and downward travel, equal in length to the stroke of the rams, can

therefore be given to the links by the forward or backward movement of the hand-lever. From Plate 5, Figs. 5 and 6 it will be seen that the links are jointed with rectangular flat plates, and as all links and plates are made of equal length, it follows that if suitable pawls are fixed to the cradle, and arranged to gear with the ends of the joint-plates, the cradle will be drawn up at each upward stroke of the rams, while during the downward motion of the links the pawls will slip, the cradle remaining in its highest position, being held by the pawls in gear with the rack cast on the centre line of rails. The hauling pawls, of which several sets are used, are shown in elevation in Plate 1, Fig. 6, and are made of forged iron secured to the main rib by cast steel or malleable cast-iron brackets. With this system no disconnection or removal of links or bars is required. The only loss is the time occupied in the return stroke, which however is not great, as, owing to the small size of the ram, it is forced out much more rapidly than are the hauling-up rams, the respective areas being approximately as 1 to 19. During the short time the links are stationary, *i.e.*, at the reversal top and bottom, water under pressure is accumulated, to be given out so soon as the rams are permitted to travel in one direction or the other.

It is obvious that several modifications of this hauling machinery can be made, all involving the upward and downward movement of the links as described, and in some cases the rams might be worked direct from a set of force pumps. The accumulator is, however, convenient not only as a means of economising time, but as a safety-valve to present shocks, and as a regulator for adjusting the speed of the engine or the working of the pumps, according to the demand for water.

A few years ago Messrs. Hayward, Tyler and Co. constructed a hydraulic hauling-gear with a double set of cylinders and rams. These were so arranged that while one set was in upward motion the other was returning. By attaching the hauling links first to one set of rams and then to the other the cradle was drawn up by an almost continuous motion. This arrangement would seem to be very costly in machinery and foundations, and would occupy considerable space, which the Authors venture to think would not be compensated by any advantage over their cheaper system.

More recently Messrs. Day and Summers have made hauling machinery in which an engine, working through gearing on to a large drum, rolled up a wire rope led from the cradle. This plan will no doubt answer well for moderate weights, but it is open to objection when applied to vessels of large dimensions, both on

account of the difficulty in making gearing to withstand such enormous strains, and in obtaining wire rope sufficiently large, pliable, and durable.

The stress required for hauling up a vessel varies very much according to the efficiency of the ways. If everything was rigid it would be found by the following formula:

$$S = \tan\theta\,(w + w_1 + w_{11}) + \frac{(w + w_1)\,r_1}{r} f + w_{11} f_1 \quad . \quad . \quad (1)$$

where S is the total pull on the links, w the weight of the vessel, w_1 that of the cradle, and w_{11} that of the links, all in tons, θ the angle made by the rails with the horizontal, r the radius of the rollers, r_1 the radius of the roller-axle, f the coefficient of friction between the axle and its bearing, and f_1 that between the links and the rails. The total amount of pull to be provided in the hauling cylinders, supposing the Authors' gear to be used, would be this quantity S, added to the total pressure on the returning ram, and what is required to overcome the friction of the hydraulic apparatus.

As in practice the values of f and f_1 are difficult to determine, and vary according to the state of lubrication, and as there is besides another unknown element in the shape of the extra pull to overcome the effects produced by deflection of the ways, it is usual to estimate the hauling power in a much more empirical manner. The following rule, constructed from actual observations, is fairly accurate for ways of an inclination of about 1 in 20:

$$S = s + \frac{w + w_1 + w_{11}}{8} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

s being the total pressure on the returning ram. For other inclinations some allowance must be made on one side or the other, but as the friction due to the weight of vessel and cradle and of the hauling gear does not vary with change in gradient, the total pull is not as a rule subject to great alteration for a given size of vessel. It also depends as much on the efficiency of the ways as on the average inclination. The time occupied in placing a vessel upon the cradle may be taken at about one hour, while the hauling up as a rule will occupy two hours, but this of course will vary according to the system employed, the length of way, and the engine power at disposal. In a slipway on the Authors' plan at Penarth, the length of ways is 867 feet, and the expense of placing and hauling up a vessel weighing 2,300 tons may be taken as the wages of sixteen men for one hour and three men

for two hours, while with Morton's system, in which the links had to be disconnected, at least another hour and a half would be taken in hauling up, and the labour of twenty men would be required during the whole operation, lasting four and a half hours. The engine power at Penarth is about 40 indicated HP., the water being supplied from the hydraulic pumping engine at the adjacent docks. Since the slipway was set to work in 1879 no less than one hundred and thirty ships have been hauled up and repaired, without the slightest accident, beyond the breakage of a few rollers at first starting.

Whatever form of hauling gear be adopted, it will generally be of advantage to have a supplementary engine and crab, with chain for traversing the empty cradle quickly up and down, especially in positions where there is likely to be an accumulation of mud at the lower end of the ways, in which case the empty cradle when run down would not acquire enough velocity to overcome and remove the obstruction.

This Paper would be incomplete without some statement as to the cost of constructing such works as have been described; but the Authors have much difficulty in giving any general estimate which is not likely to be misleading. It may, however, suffice to state that a slipway such as that shown in Plate 5, Figs. 1 and 2, could be constructed for about £25,000, including the foundations, 850 feet of ways, cradle, and appurtenances, hauling machinery with links, and one timber side jetty, but exclusive of land. The gradient is 1 in 19; and the machinery is sufficiently powerful to haul up a vessel of 2,500 tons gross weight. The slipway could accommodate two vessels, each about 280 feet long, at one time.

In conclusion it may be mentioned that the Authors do not advocate the indiscriminate adoption of slipways in every case where it is desired to set up a ship-repairing establishment. They believe that the choice of the plant, whether it is to be a graving dock or slipway, a floating or hydraulic-lift dock, must rest entirely with the engineer after a careful survey of the locality and a consideration of his resources. In very many situations, however, there can be no doubt that as regards first cost and facility in execution the slipway possesses advantages which should specially recommend it to capitalists, while from the shipowner's point of view the better ventilation around the vessel when it is withdrawn from the water, the ample opportunity afforded for inspection, and the short time occupied in hauling up and launching, neither of which operations is necessarily de-

pendent on the tide, except in very special situations, are all important features. It is probably the combination of these advantages which has led to the financial success that the Authors believe has attended the working of every well-constructed and conveniently-placed slipway; while on the other hand there is, unfortunately, little room for doubt that in many instances graving and other repairing docks have been a source of considerable loss; though, as was pointed out by Mr. T. Stevenson, M. Inst. C.E., in his work on "The Design and Construction of Harbours," they largely tend to raise the character of a port, and hence almost all harbours of any importance have them.[1]

In this Paper only such methods as are generally in use have been dealt with, and no attempt has been made to describe the obvious designs of greater or less utility which might be desirable under special circumstances. Such are the hauling up of the vessel broadside, as has been carried out at Bordeaux by Mr. Labat, and the provision of a traversing carriage for shunting from the main ways, to enable several vessels to be slipped where length cannot be obtained to accomplish it in the usual manner. Reference should, however, be made to the combined floating dock and slips as first carried out in 1851 at Philadelphia and afterwards at Portsmouth, U.S.A., and at Cartagena and Pola.[2] The dock at Philadelphia was designed for lifting vessels up to 2,800 tons gross weight and about 300 feet long. There were two slipways placed side by side, each served by the dock, and capable of berthing one vessel, but the cradles were not provided with rollers. The time occupied in operating on a vessel was two hours for lifting and seven hours for hauling on the slip, while the launching took nearly as long. The total cost of dock and slipways was about £163,000.

It might be worth mentioning that by having two slipways side by side, each complete in itself and capable of dealing with two ordinary vessels, they could be arranged, if necessary, to act together so as to haul up jointly one large ship such as an ironclad.

The Paper is accompanied by several diagrams from which Plates 5, 6, and 7 have been prepared.

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[1] Second Edition, p. 164.

[2] Minutes of Proceedings Inst. C.E., vol. xxxi., p. 295; and xxxii., p. 65.

Discussion.

Mr. Bruce Bell. Mr. ROBERT BRUCE BELL observed that he had been engaged in the design and construction of slip-docks for the last thirty-six years. The inventor of the slip-dock was the late Mr. Thomas Morton, as the Authors had stated, and the main features of the slip-dock remained much as he had left them. The first actual change was made upon the purchase-machinery or hauling power. The original machinery consisted of spur-gearing, driven by manual power, horses, or the steam-engine. The change was the substitution of the hydraulic ram for the spur-geared winch, but the Authors were mistaken in ascribing this invention to Mr. Morton, who died many years before. The invention was that of Mr. Daniel Miller, M. Inst. C.E., and was patented by him in 1849. The first application of it was on the slip-dock constructed by Mr. Miller and himself at Kelvinhaugh, on the Clyde, in the year 1850, the hydraulic machinery and cradle being made by Messrs. Samuel and Hugh Morton. This slip had taken up vessels of 1,000 tons. The length of stroke of the ram was 15 feet; the pumps were driven by a 30-HP. engine. Shortly after the completion of the Kelvinhaugh slip-dock, another dock, with hydraulic purchase for vessels of 1,500 tons, was laid down at Melbourne for the Colonial Government, and about twenty-six years ago a large hydraulic purchase was designed and constructed for the Russian Government for war-vessels of 2,000 tons, and another slip of equal size was sent to the Mauritius; but the largest hydraulic purchase on Miller's patent was that made for the Egyptian Government for war-ships of 3,000 tons. The stroke was 15 feet in length, the ram 18 inches in diameter, the weight of the cylinder 17 tons, that of the ram 5 tons, and the side-rods were each 5 inches in diameter. Various other slip-docks on this principle had been constructed with various lengths of rams, but the handiest length of stroke appeared to be 10 feet; the rods were whipped out of place by a crane, worked by steam or hydraulic power, and stacked at once; a couple of men were all that were required for fleeting the rods, and no such expenditure of time as that stated by the Authors should be necessary in a properly arranged dock. No separate engine was required for hauling up the empty cradle, this being done by gearing attached to the hydraulic apparatus; various modifications had been made upon the hydraulic apparatus since it was originally designed by Mr. Miller.

In the description of the mode of relieving the cradle from the ship in order to take up another vessel astern, the Authors observed that this was "an improvement which had been introduced of late years," and they went on to state that the transverse arms, "instead of being permanently fixed, are hinged at their outer ends to the side-ribs, and are thus capable of being swung round parallel with the side-ribs, upon which they rest when in this position," and they then described the process of relieving the cradle. He could not say whether Mr. Thomas Morton originally fixed the arms in a permanent manner, but he could say that he had never seen one of Morton's cradles with arms so fixed; and he knew that in the cradle furnished by Messrs. S. & H. Morton for the slip-dock constructed by him at Stornoway, thirty-six years ago, the arms were not so fixed, and that he relieved the cradle in precisely the same manner as described by the Authors (with the exception of swivelling the arms and lifting with hydraulic presses), and lowered it astern to take up another ship. In fact, all Morton's cradles, long before this time, were relieved in this manner. As regarded the swivelling of the arms, and the introduction of hydraulic presses to relieve the keel, both systems had been in use on the Clyde for upwards of thirty years. The first set of these swivels were fitted upon the cradle of the Kelvinhaugh slip thirty-three years ago; the cradle was also fitted with a set of Scott's keel-blocks, which could be all started at one lift, one connecting-pipe passing through the whole set; thus the ship was eased up bodily by a single pump. In view of this he could hardly see how the mode of relieving the cradle as described could be claimed as "an improvement introduced of late years." Another improvement which had been made upon slipways by himself was the provision of gates, by which a shorter length of slipway was required. The great length of slipway extending under water, and consequently valueless, was one of the chief drawbacks of a slip-dock. The first design for a dock on this system was made for the Nelson slip-graving dock at Rotherhithe on the Thames in 1854, and was constructed in the following year. Another novel feature in this dock was the form of the ways, which in place of being laid on a straight incline were laid upon a curved incline, the bottom of the cradle being shaped to the same curve, the ways concave and the bottom of the cradle convex. The reason for introducing these modifications was, 1st. For the adoption of gates. The shortness of the available length of ground, laid out at the requisite inclination, brought the level of high-water up to the door of the purchase-house; gates were therefore put in at the river line, Mr. Bruce Bell.

Mr. Bruce Bell. which were shut, as in a graving dock, after the vessel had been hauled up, and the water had ebbed. 2nd. For adopting a curved line, in place of a straight line of vertical inclination, was to avoid the great cost of sinking into the bed of the Thames to the depth required for the extreme end of a straight incline, and the certainty of constant deposit of mud at such a depth. It might be asked why not have made a graving dock at once? The answer to this was the expense of excavation, and the constant expense, at every opening of the dock, of clearing out the mud brought in from the river, and the cost of pumping, all of which evils were avoided in the dock as designed. This dock was unique of its kind, both in design and cost, the latter having been about £5,000. At high water the tide came up to the purchase-house door, and the total length of the slipway was only 356 feet. On the ordinary mode of construction it must have been 500 feet at least. Another dock, combining the dry-dock and slip-dock, was that constructed at Meadowside on the Clyde. It was laid on a straight incline, and had ample room above high-water mark; but to gain the use of some of the submerged portion of slipway, a chamber for the reception of a caisson was placed a little above the low-water line. This slip received vessels of 1,500 tons. The cost of this dock was about £18,000, that of Kelvinhaugh Dock was about £10,000. Complete plans for a graving slip-dock with caisson were made in 1859, and were sent to Stettin to be erected by a Prussian engineer. For a long time after the introduction of slip-docks, the vessels for which they were intended not exceeding probably 300 or 400 tons, and the beaches upon which they were laid (principally on the east coast) having a good range of tide, rendered the laying of the ways a comparatively easy operation by tidal work; but when larger ships came to be provided for, and slip-docks to be built on the Clyde with a range of only 9 or 10 feet of tide, the work of laying the outer end of the ways became difficult. The construction of a cofferdam was too serious a matter to contemplate, and in the first slip-docks constructed on the Clyde, those for Messrs. Barclay, Curle & Co., about forty years ago, the lower ends of the ways were laid upon a long platform of timber, as described by the Authors, and were sunk upon a bed prepared for them by dredging. This was also done with the Kelvinhaugh slip, the platform being about 300 feet long, but in some of the larger slips since made in the Clyde and elsewhere, a much stronger framework of timber was required; and in the case of the Meadowside slip, the bed had first to be piled, and the pile-heads cut off to the required line by sawing under water, and the frame-work set on

top of them. The best foundation for the upper end of the large slip-docks where not water-borne, and in fact for the whole of the slipway if made within a cofferdam, was ashlar stones set continuously upon solid masonry or concrete, and the cast-iron rails laid upon them without any timber intervening, the rails accurately fitted to the stone and bedded on flannel soaked in tar. The action upon the rails being a continuous steady motion by rollers of small diameter, closely set together, required a firm unyielding foundation. Mr. Bruce Bell.

The advantages and disadvantages of a slip-dock as compared with a dry-dock were less cost, better circulation of air around the vessel, better light, and no pumping for leakage. Against greater length of ground occupied, the larger amount of scaffolding required, and the great depth to which the after end required to be sunk beyond what was necessary for the draught of vessel. Where ground was of little value, and ample length could be obtained without inconvenience, the great length required for slipway was of little consequence; but where ground was valuable, and powers could not be got to project the slipway into the harbour or river, it became a more serious consideration. In the case of a dry-dock the only portion of the works unavailable for dock-floor was the entrance and gate chamber, not many feet in all. But in the case of a slip-dock a very large extent of dock-floor was rendered valueless. For example, supposing a slip were required for vessels 300 feet in length, such a vessel could be trimmed with ballast so as to have only 11 feet depth of water at the bow, about 3 feet more were required for the cradle and keel-blocks, or 14 feet in all, as depth of water on the rails, at a point 300 feet from the extremity of the slipway. The inclination of the ways would be 1 in 18; this would give $14 \times 18 = 252$ feet of slipway covered with water in advance of this point, which, in addition to the 300 feet, made 552 feet in all covered by water. Of this 50 feet might be gained by allowing the vessel to overhang at both ends, and telescoping the steering pieces as the Authors suggested, but it still left 500 feet covered with water, and valueless as dock-floor. It was true that part of this was generally utilised by allowing the last vessel docked to remain on the cradle to be operated upon by tide work. The choice, therefore, between these two forms of dock depended much upon local circumstances and the means at command. In order to gain additional surface of dock-floor, vessels requiring extensive repairs had in some cases been removed bodily to one side of the slipway. Messrs. Barclay, Curle & Co. worked their slipways on the Clyde

Mr. Bruce Bell.

for many years in this manner, and in some cases built new vessels on the side of the slipway, and launched them by removing them on to the cradle.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL said he did not know that he had much to say on the subject of the Paper, but it touched incidentally upon other modes of raising vessels for repair, in which he had some experience. He might say after Abernethy, "Read my book," as he believed that the history of the matter, both with regard to slips and to other modes of repair, had been fully dealt with by himself in a Paper read before the Institution of Mechanical Engineers in 1867.[1] It might be interesting to mention a mode of docking ships for repair mentioned in Belidor's "Architecture Hydraulique," in which he suggested that, in lieu of the expense of pumping out a dry dock below the level of the water, there should be, in places where there was a sufficient supply of inland water, a lock made, into which the ship would be floated, and then, the inland water coming in and raising it, it was to be taken into a higher lock, and, the gates being closed, the water was to be allowed to run down; that was a mode of raising the ship out of the water instead of pumping the water away from the ship. There was a good engraving of it in the excellent edition of the book which was in the Library of the Institution. With regard to the telescopic arrangement of the cradle of the slip, the employment of hydraulic power, and the other matters mentioned in the Paper, they were, according to his recollection, quite accurate. Slips and dry docks were useful in cases where there was a suitable foundation; but there were places in which it was desirable to repair a ship where it was impossible to get a good foundation, and in such places it was necessary to resort to a floating dock. He did not think it was possible to make a floating dock at the same small amount of cost for which a slip could be made where there was a good foundation; but it was perfectly possible, by means of a floating dock, to raise very readily the largest ship, to get it up in a short time, to repair it, and to lower it again with regularity and success. A dock that he designed twenty years ago, had been at work for many years at St. Thomas's, in the West Indies, and although curtailed of its original dimensions, it was still competent to raise 3,000 tons dead weight with facility. The sides of the dock were not closed in the manner of an ordinary

[1] Institution of Mechanical Engineers. Proceedings, 1867. "On floating docks and other arrangements for affording access to ships for external repairs," p. 80.

dock, but were open-girder work, and the lateral stability of the dock was obtained by means of floats which worked within the girder-work, and which might be said to rise and fall within that work, the fact being, that the floats remained on the surface of the water, and the dock rose and fell past the floats. The sides being open, there was as much ventilation for the workmen employed, as there was when the ship was upon a slipway. Mention had been made of hydraulic keel-blocks, all coupled together, and subjected to one pressure. He knew that they had been used in London in the floor of an ordinary dry-dock; but he believed they were abandoned because they were found to strain the ship. The notion was to give the ship an elastic bed, and thus to prevent strain; but it would be seen on consideration that blocks of that construction must cause strain because they were all coupled up and were under one pressure, so that if they were all of one size they all had an equal tendency to rise out of the presses in which they were placed. Therefore, whether the part of the ship over them weighed much or weighed little, the upward tendency of the block being the same, the ship had to keep down the block, say at the ends of the vessel where the weight was little, not by the weight of the ship itself, which it could not do, but by acting as a girder, and transmitting to the keel-block so situated a portion of the weight which resided in the central part of the ship. He believed it had been found better to get rid of that water-bed for the ship to lie upon, and let it bear upon rigid points of support at intervals along its length, and he thought that the water-bed difficulty was one of the reasons why the original sectional floating-dock in America, which he saw last autumn, after an interval of thirty years' working, just as it worked thirty years ago, had never met with so much favour as the more rigid slipway, or the more rigid complete floating dock, where a firm floor could be given for the ship to bear upon, although, no doubt, at first sight, the floating support appeared to be one which might accommodate the patient in great comfort. Sir Frederick Bramwell.

Mr. A. Giles did not think the advantages were as great as had been suggested in the Paper. It was called a primitive form of repairing vessels, and the Author went back as far as the days of Carthage. He thought that a slipway, notwithstanding all the ingenuity of the hydraulic process for lifting ships, was a primitive form, and he demurred to the statement that it was applicable to vessels of the largest class. He concurred with Sir F. Bramwell as to the necessity of having a rigid foundation for the keel of a ship. The Authors insisted that where the foundation Mr. Giles.

Mr. Giles. had to be made partly on piles and partly on the ground, there was a liability to settlement or fracture at the points of junction. He quite agreed with that statement: what then must be said as to the foundation that the Authors proposed to lay below the water-line by dredging out a trench, by casting stones into the bottom, and by laying the floating platform thereon? Was it to be supposed that that could be rigid and perfectly true for the purpose of hauling a vessel up? He thought there must be a practical difficulty in laying a slip below the water without a cofferdam, a difficulty that had not been sufficiently explained. He admitted that at such a place as Penarth, where the range at spring-tides was 39 feet, and at neap-tides 29 feet, it would be easy enough to make a good foundation on the shore, but how many ports were there in which there was such a range of tide, and where it was not wanted to dock or repair vessels drawing more than 12 feet depth. There were many ports with less than 12 feet rise of tide, and that being so, there must be a foundation not laid under water upon a heap of stones, but properly laid by means of a cofferdam, which was something very near what was called a dry dock. The Authors also spoke of another plan applicable in situations where there was a sufficient range of tide to enclose the upper part of the slip within watertight walls, provided at the bottom with gates. That statement simply meant a dry-dock; and showed that the system of slips was not quite satisfactory for the largest vessels. The time of getting a ship on the cradle had been taken at one hour, and the hauling up at two hours, but in another place the time had been given as about four and a half hours. If a slip-way was laid upon the shore in an exposed situation, as it must be in some places, and would perhaps be at Penarth, it would depend upon the weather whether the ship could be accurately fitted on the cradle before the process of hauling commenced. It was said that since the slipway had been at work in 1879, no less than one hundred and thirty ships had been hauled up and repaired. Taking the time thus given as three and a half years, that would be at the rate of one ship in about ten days. In going into the question of finance, the Authors stated that the slipway would cost £25,000, and that it would be much cheaper than a dry dock. Mr. Giles could only say that many years ago he made a dry dock, which would do all that the slip in question could do, for less than £20,000. Before the slipway was regarded as a financial success, the figures should be examined. Five per cent. upon the cost, £25,000, would be £1,250, and the expenses and repairs might be taken at £1 a day, say, in all £1,600. On

that basis as the cost of docking thirty-five ships, the expense was nearly £50 a ship, a large price for docking a ship of the size mentioned, and he ventured to think that a good many shipowners would object to pay £50 for such an operation. He should like to ask whether, when the Authors spoke of the financial success of the undertaking, they did not include repairs with the charges for hauling up. Another large dry-dock establishment, not far distant, had for many years been worked without profit, until the proprietors took to repairing, and since then they had done very well. Mr. Giles quite agreed that a vessel hauled up had better ventilation, and everything could be better seen than in a dry dock; but in reference to the time required in the dock, it should be borne in mind that the repairs now required for steamships were mostly connected with painting. Iron steamships—and nearly all steamships were now of iron—required docking for painting almost every voyage, certainly every three or six months, and for that purpose they need not be in dock more than two or three days. The average time in dock of a number of vessels in which he was interested was about three days, so that to make a system successful it would be necessary to get vessels in and out once in every three days. The Authors had compared their method with a plan adopted in Philadelphia, at a cost of £163,000. He could not conceive any dry-dock for the purpose of accommodating vessels of the class above mentioned costing so much money. He thought that the objections to which he had referred increased with the size of the vessels. It had always struck him that there was a point at the launch of a ship where it encountered an enormous strain, namely, when she was going off the ways, and the stern was floated while the bow of the vessel hung on the ways. The strain occurring to a ship of great length must be very considerable, and no doubt had necessitated a great increase in the strength of the keelsons and bottom plates. He thought that Mr. Brunel felt that objection when he hesitated to launch the "Great Eastern" end on, and had launched her broadside. He therefore thought that a long vessel, being hauled up the slip, would to a great extent suffer a strain from her stern being afloat while her bow was held fast in the cradle. Of course with vessels of ordinary size the strain would not be so much felt, but with vessels 400 or 500 feet long, he thought the objection a serious one. Mr. Giles.

Mr. G. W. Rendel said he had considered the subject of slipways for gunboats and other small ships of war, and he certainly thought he saw advantages in the proposals of the Authors as regarded some of the mechanical arrangements, especially those Mr. Rendel.

Mr. Rendel. to enable the removal of the links to be dispensed with. He had not considered the use of slipways for very large vessels, but he thought there must be great difficulty in finding any site adapted for the very long incline to be made under water, especially where there was no rise and fall of tide. For large ironclads he should say that it would be quite out of the question to compare a slip of that description with a stone dry-dock, or some of the other well-known systems of floating dock. For such purposes as storing gunboats, slipways were evidently well adapted, especially if arranged so that, after drawing up one vessel, they could deposit it and proceed to draw up another. Such small vessels, which were not wanted except at long intervals, could be kept in a better state of repair, with their bottoms always clean, on shore than afloat.

Mr. Owen. Mr. G. Wells Owen observed that reference had been made to the fact that Mr. Brunel had launched the "Great Eastern" sideways instead of lengthways. Mr. Owen wished to add that in 1860 he was engaged in constructing the gridiron on which the "Great Eastern" was laid up after her first voyage. It was laid on the shores of Milford Haven, and consisted of balks of timber laid transversely, and fastened down by short piles of timber, or in places where the timber could not be driven, of iron, into the rocky shore at low water. The ship was brought up broadside on, and laid on the gridiron in that way. He had no doubt that Mr. Brunel, in so designing the gridiron, acted on the same principle as in launching the ship.

Sir Charles Hartley. Sir Charles Hartley said that towards the conclusion of the Paper the Authors had stated that they did not advocate the indiscriminate adoption of slipways in every case where it was desired to set up a ship-building or a ship-repairing establishment, but considered that in many situations, with regard to first cost and facility in execution, the slipway possessed advantages which should specially recommend it to capitalists. That modest claim almost disarmed criticism, for it was undeniable that in many places the establishment of slipways for the repair of vessels of moderate size was a good and cheap substitute for dry or floating docks. When, however, it was asserted that "Since then the improvements introduced have been entirely in the details of the apparatus, which, from being at first merely required to deal with the light wooden ships in use at the commencement of the present century, is now constructed for speedily withdrawing from the water the largest existing iron vessels," one naturally inquired where such slipways were to be found, and under what

Sir Charles Hartley.

circumstances they had been built; for although slipways for small vessels were preferable as a rule to other modes of dealing with vessels requiring repair,. it by no means followed that the same remark applied to vessels of very large tonnage. It was well known that at the present day there was a perfect mania for building large ships, and that merchant vessels from 3,000 to 5,000 tons were numerous everywhere. Perhaps the Authors could state where slipways were found capable of accommodating vessels of that displacement. The only illustration given by them of a modern slipway was shown in Figs. 1 and 2 for vessels up to 300 feet in length and 2,500 tons gross tonnage, and to that example he would confine his remarks. It was obvious that in rivers, in tideless seas, and where the range of tide was very inconsiderable, such as the Mediterranean, the length of a slipway under water must be very great to accommodate the long ocean-going steamers of the present day. With a slope of 1 in 19 (which, it was said, was a suitable one for a large slipway) the submerged slipway in a tideless sea or a river at very low water must have a length, if curved ways were not used, of at least nineteen times the draught of the ship to be raised, merely to reach her stem; and, in spite of the telescopic arrangement that had been so well described, the slip would require to be further extended to at least one-half of the length of the vessel. Thus, supposing a ship to draw 16 feet and to have a length of 300 feet, the length of the slipway under water would have to be 450 feet—a most serious consideration where the provision of a rigid platform under water at every part was a *sine quâ non.* Again, such a slipway to be successful would require to be established in still water, and that without the use of jetties, which were highly objectionable in situations where strong currents prevailed. He might be permitted to refer to Mr. Labat's system at Bordeaux — alluded to in the Paper — a system of hauling up vessels broadside, and to a similar method adopted with great success at Budapest by Mr. M. Jackson, Chief Engineer of the Danube Steam Navigation Company. In some localities, and especially on the shores of silt-bearing rivers, the plan of hauling up vessels of moderate dimensions broadside on and over greased slipways, as contradistinguished from ways which had rails on them, was the best that could be adopted; and he had no doubt that Mr. Jackson would cheerfully give the benefit of his great experience on that subject. The cost of a modern slipway, capable of lifting a vessel of 2,500 tons, was said to be £25,000, exclusive of land. It would be highly satisfactory

Sir Charles Hartley.

to know what proportion of that estimate was for foundations, the most important and the most difficult part of the structure, and also the nature of the foundations. At Belfast, where a slipway was constructed in 1847 for vessels of 1,000 tons, the foundations had cost £12,000 out of a total expenditure of £17,000, the entire length being only 560 feet. It was a difficult matter to compare the cost of slipways with that of dry docks, sectional docks, and hydraulic lifting docks, unless the peculiarities of each case were well known and carefully considered. Many dry docks capable of receiving vessels of much more than 2,000 tons displacement had been constructed in this country and abroad for less than £20,000 each, although instances might be given of dry docks which had cost from four to eight times that amount. For example, the four graving docks recently constructed at Spezzia had cost £312,000, or nearly £80,000 each, and the Somerset dry dock at Malta had cost £150,000. Such cases, however, were very exceptional; and the same might be said of some of the floating docks recently constructed—notably the iron floating dock weighing 4,500 tons, constructed at a cost of £132,000 by Schneider and Co. at Creusot for Saigon in Cochin China.[1] Those costly works being expressly built to accommodate the largest men-of-war afloat, could not, of course, be usefully compared with slipways and docks built exclusively for the purposes of merchant and passenger steamers. After considering some of the advantages and disadvantages of slipways compared with other arrangements for the repair of ships, he thought it might be fairly said that, except in special cases, the provision of a dry dock was more advisable than that of a slipway in a locality where some of the vessels requiring repair exceeded a length of 300 feet or 2,000 tons displacement. That opinion was strengthened by a letter that he had received from a large firm of shipowners in the north of England, an extract from which he might be permitted to read:—"We decidedly demur to haul a ship of 350-feet length up a patent slip if a floating or a dry dock could be had. We should consider such a vessel liable to strain by being put upon a slip, although we believe that it is occasionally done, for by enquiry which we have just made we find that a steamer of 300 feet in length has been put upon the 'Wallsend Slipway' at Newcastle without any bad results whatever—but they have not had a longer one on. We may mention, however, that this slipway is of recent construction and probably one of the best in the kingdom." He fully agreed with

[1] Minutes of Proceedings Inst. C.E., vol. lviii., p. 380.

the Authors that in setting up a shipbuilding establishment, the choice of a plan should be left entirely to the engineer, after he had made a careful study of the locality, as in all such cases the chief merit would deservedly belong to those who, after a long and patient study of different systems on the ground, chose the method best adapted to the special circumstances of the site where economical first-class ship accommodation was urgently needed. Sir Charles Hartley.

Mr. J. B. Redman said the value and interest of the Paper would have been considerably enhanced if the Authors had given the tonnage, also the names and dimensions of the largest vessels that had been dealt with by the ingenious systems which they had described. After carefully reading the Paper, he had been unable to arrive at a conclusion as to what was speculative, and as to what had actually been done. He presumed that the example given of a slipway for vessels of 300 feet length, and 2,500 tons, was intended to illustrate the system advocated by the Authors. No doubt if vessels of 4,000 or 5,000 tons (which were becoming so common) could be raised upon slipways and repaired in the same manner as in dry docks, there was manifestly the advantage of light and ventilation; but, on the other hand, the old system of graving-docks gave a level keel, and greater facilities for shoring, as compared with slipways. The objection to a slipway for raising vessels of great weight was met by the advocates of the system by saying, "That is true; but the modern iron vessel is, in the first instance, launched on crossways of a very similar character." No doubt that was so, but the vessel, until she was launched, was in the hands of the naval constructor, and the launching of the vessel was perhaps one of the most crucial epochs of its existence, and launching from the shipwright's ways appeared to him to be a very different operation from that of re-hauling the vessel on to *terra firma*, up a slipway, for the sake of repairs. The Authors had referred to the obvious disadvantage of piling, intermixed with ground of a yielding nature; but he thought they had been rather ungrateful towards a system which had formerly been used in all naval constructions, such as docks, lock-pits, slipways, and other structures where the mass of work rested upon piles. Although the foundations for such works, in the majority of instances where the materials were at hand, were now formed by masses of concrete made with Portland cement, which were got in at a much greater depth owing to the improved mechanical advantages of the present day, still there were situations, especially in the Colonies, where, even at present, piling must be resorted to. To put piling on one side altogether, appeared to him rather to ignore a method that had done good service in constructions of that kind. The Authors Mr. Redman.

Mr. Redman. stated, "After the first starting of a slipway, slight settlements are sure to take place, but are easily compensated by wedging up the rail-bearers when required." He thought that paragraph was very suggestive as to the increased difficulty there would be either in hauling up or in launching a vessel of 5,000 or 6,000 tons, like the "City of Rome." No doubt piling for such purposes was objectionable. There had been an example, on a large scale, in the very great difficulties that occurred in the launching of the "Great Eastern." Notwithstanding all the calculations made with the greatest accuracy, and the care taken with the piling and the preparation of the bed for the broadside launching of that vessel, he believed it was generally acknowledged that it was the slight inequalities arising from the greater bearing power of the piles as compared with the intervening spaces, the very slight irregularity produced thereby, and the increased friction and resistance to the moving mass, that caused Mr. Brunel so much trouble, and possibly hastened the termination of his career. The Authors had further stated, "In a slipway on the Authors' plan at Penarth, the length of ways is 867 feet, and the expense of placing and hauling up a vessel weighing 2,300 tons may be taken as the wages of sixteen men for one hour, and three men for two hours." He should be glad to know whether that was a hypothetical case, or whether such a vessel had actually been handled. The Paper also stated—"Since the slipway was set at work in 1879 no less than one hundred and thirty ships have been hauled up and repaired, without the slightest accident, beyond the breakage of a few rollers at first starting." It would be interesting to know the tonnage of the largest vessel so handled. The Authors had further stated, "There is, unfortunately, little room for doubt that in many instances graving and other repairing docks have been a source of considerable loss." Undoubtedly they were a source of loss when they were dry docks or graving docks only by courtesy, and leaked exceedingly. There were docks on the Thames, constructed mainly by the owners of the yards, that leaked like a sieve, and the consequence was that they were not a very profitable enterprise; but he could give many examples of docks that had been the mainstay of families for three generations, who had lived in opulence upon them. It was a serious charge against graving-docks to say that they had generally been a source of loss. It was also very suggestive, that although the bill for the first great Metropolitan dock—the London Dock—contained a clause for constructing dry docks, the "long shore" interest expunged it, and so with all its successors until the Victoria Docks first obtained the necessary powers. No doubt if vessels of 5,000 tons could be hauled up and launched

in the way proposed, shipowners would be glad to avail themselves of them at the reduced cost; but when there was a dry dock into which ships could enter without risk, whether the charge was double or treble, they would probably prefer the dry dock. Everybody knew that even taking a vessel of that tonnage into a floating-dock, especially in a gale of wind, was a rather nervous process, but what would it be to haul a vessel of that description up an incline of 1 in 20? Mr. Redman.

Mr. W. B. Lewis observed that it ought not to be taken for granted that every one admitted that the "Great Eastern" was stopped in launching by any settlement in the ways. Mr. Lewis.

Mr. Redman supposed the stoppage arose from irregularities in the resisting medium forming the ways, which created a variation in the friction to the moving mass. Mr. Redman.

Mr. T. Summers said it was stated in the Paper that his firm had made hauling machinery, which "will no doubt answer well for moderate weights, but it is open to objection when applied to vessels of large dimensions, both on account of the difficulty in making gearing to withstand such enormous strains, and in obtaining wire rope sufficiently large, pliable, and durable." The first slipway on which their system of wire-rope haulage had been used, was on their longest slip, which was set to work January 1879, and had been constantly in use ever since. The ground-ways were on an incline of 1 in 24, and were 622 feet in length, the cradle being 221 feet long, and 82 tons in weight. The engines which worked the hauling gear had two cylinders, each 10 inches in diameter and 12 inches length of stroke, fitted with link motion for reversing them. A worm on the engine crank-shaft, geared into a worm-wheel having fifty-six teeth, and that drove a shaft carrying a pinion with fifteen teeth and 4-inch pitch, which geared into a spur-wheel with ninety-five teeth, to which was bolted the large barrel, which thus made one revolution whilst the engine made three hundred and fifty-five. A smaller barrel, keyed on to the first-motion shaft, was found very useful for hauling up the empty cradle, or for small vessels, and, as it ran six and a third times as fast as the large barrel, it saved much time. The importance of such a means of hauling up the empty cradle quickly had been alluded to in the Paper, but of course, with hydraulic gear such an apparatus would be an additional complication and expense, whereas on the system referred to, that supplementary barrel was only a small portion of the winch. The large barrel was 5 feet in diameter, and 7 feet 3 inches long, and wound on itself a steel-wire rope 9 inches in circumference, and manufactured Mr. Summers.

Mr. Summers. by Messrs. Bullivant, who guaranteed its ultimate strength to be not less than 180 tons, although they believed it would not break under a strain of less than 200 tons. They had hauled up vessels on this slip, some weighing 1,000 tons, which added to that of the cradle was equal to 1,080 tons, giving 45 tons theoretical pull on the hawser. Their experiments showed that the friction was about 50 per cent., which gave 67½ tons pull on the hawser, or a factor of about one in three. The wire rope after four years' usage was as good as when first set to work. The next slipway on their system was that at Ayr, designed by Mr. J. Strain, M. Inst. C.E., to haul up vessels weighing 1,200 tons, with a cradle weighing 150 tons, and worked by a 12-inch wire rope, also supplied by Messrs. Bullivant, and guaranteed to have a breaking strength of 360 tons. The third slipway where wire rope was used for haulage was their own smaller one. This had been worked for many years with ordinary chain, and, as that was found to be a slow process in consequence of the frequent "fleets," and as the links of the chain when passing over the barrel always bent, and frequently broke, they determined to alter the steam winch to suit wire rope. That had been successfully done, and much heavier vessels than before were now handled by the introduction of a large sheave fixed to the end of the cradle, giving two parts of rope instead of one, with the standing part fastened to an anchor-bolt in the foundation under the steam winch. The rate of haulage with the single part of rope was from 12 to 20 feet per minute, according to the weight of the ship, and vessels had been frequently hauled up in forty minutes after they were blocked. The saving in time and expense of this system, as compared with the hydraulic method, was considerable, and on the first cost probably one-half or one-third. By the introduction of the sheave at the end of the cradle, and so hauling by two parts of the wire rope instead of one, the hauling power was doubled, and, if necessary, a second pulley could be introduced, and the hauling power thus multiplied three-fold, without putting any more strain on the wire rope or the gearing of the steam winch. For instance, it was contemplated to fit the system to a slip suitable for vessels weighing 3,000 tons, to which must be added the cradle weighing 250 tons, or a total of 3,250 tons. Adding one-half for the friction of the cradle, would give a gross of 4,875 tons, on an inclination of 1 in 24, producing a strain on the wire ropes of 203 tons. Messrs. Bullivant guaranteed a strength of 360 tons with a rope 12 inches in circumference, so that two parts of such rope would have 720 tons of ultimate strength. Then 720 tons, divided by the strain

of 203 tons, would give a factor of safety of three and a half. As before remarked, that could be increased by adding another sheave, so that vessels weighing 4,000 tons could be easily hauled up. If a small or light vessel had to be hauled up one part only of rope would be used, and the ship would come up rapidly. But, by the hydraulic system, a small and light vessel took almost as long to haul up as a large and heavy one, because of the delay by the reciprocating action of the hydraulic ram whereby one-half in time was lost, and also by the time taken up in "fleeting." Thus if the cradle had to be moved 600 feet, and the hydraulic ram moved 10 feet, there would be 60 fleets, which, at three minutes each, would occupy three hours for "fleeting" only. He thought the system of steel-wire haulage for slipways possessed several important advantages over any other yet introduced, as it was much less expensive to lay down, less costly to work, more rapid in its action, and could be employed for any sized vessel. Mr. Summers.

Sir John Coode was pleased to have his view confirmed that a repairing slip was a good thing for vessels up to about 2,000 tons, but he quite agreed that for vessels beyond that tonnage, a dry dock was in every sense preferable. The mode that had been described of laying the lower end of the platform was, in his opinion, so far as he could understand it, not a satisfactory proceeding. He knew the difficulty attending such an operation; but he thought that to sink the platform by merely weighting it with stones, and letting it down upon a dredged bed, which had been equalised by a layer of rough rubble stone, was not a satisfactory engineering operation. Where the rise of tide was considerable, and the means of laying the full length of the slip in the dry existed, a repairing slip might be used with advantage for vessels of a moderate size. In his own experience, he had to lay the foundation of a slip in an excavation, which had been laid under a cofferdam and dried, and there the foundation from top to bottom was rock. The rails being laid upon a solid rock, with a thin bed of neat Portland cement intervening, the operation was most successful. But where the range of tide was small the only thing that, in his opinion, would enable an engineer to lay a satisfactory foundation, and that would warrant a shipowner in placing a ship on it, would be to construct a dam and lay the foundation entirely in the dry. That, of course, meant a dam of considerable length; and in an operation of that kind, the difference in expense between a repairing slip and a dry dock almost, if not entirely, vanished. A slipway was excellent for a young growing port, and for vessels of a limited size, but for Sir John Coode.

Sir John Coode. vessels of 4,000, 5,000, or 6,000 tons, a dry dock was the only safe and proper thing that an engineer could recommend. Looking at the matter all round, it might be said that a repairing slip was good, but that a dry dock was better. He should be glad to know if the wire rope was an endless one.

Mr. Summers. Mr. T. SUMMERS replied that one end of the rope was fastened to the cradle, and the other to the drum. A light vessel, say up to 1,500 tons weight, could be hauled up without stopping, but when a much heavier vessel was hauled up part of her length, the rope would be passed round a sheave at the end of the cradle, making the second part. There was no sheave at the bottom of the slipway. The diameter of the drum, for the 12-inch wire rope, was 9 feet. Their own rope was 9 inches; the pitch of the crown-wheel, working the drum, was 4 inches; the diameter was 10 feet, being twice the diameter of the drum.

Mr. Lightfoot. Mr. T. B. LIGHTFOOT, in reply upon the discussion, said that Mr. Bruce Bell's remarks consisted chiefly of extracts from a paper read by him before the Institution of Engineers in Scotland in December 1858, and related more to questions of priority of design than to any criticism on the Paper. No doubt Mr. Miller was the inventor of the hydraulic hauling-apparatus described as having been introduced by Mr. Morton, though it generally went by the name of Morton's gear. He was not aware that the method of relieving with hydraulic cylinders was used so long ago as the year 1850; but in that also Mr. Bell was doubtless correct. With regard to the time in fleeting on the old system, where the rods had to be disconnected and removed, he could only say that the times given had been taken from actual work at a slipway erected by Messrs. Morton in 1874, and he believed they correctly represented the average, though of course, in some cases, the vessel was more quickly placed than in others, while, if the weight was small, the hauling up took less time than if the full power of the machinery was being exerted. He had read Sir Frederick Bramwell's paper on the floating dock built for the Island of St. Thomas, and other methods of docking vessels for repairs, with much interest, and would have named it in their communication had it not been that slipways were only mentioned in it incidentally, in common with careening and other systems. The same speaker, as well as others, urged the necessity for having an absolutely rigid support or floor for the vessel in place of one of a slightly yielding nature. He regretted that no reasons had been given for that preference, for unless it could be demonstrated that

Mr. Lightfoot. the majority of vessels of the present day had perfectly straight keels, it seemed to him that a rigid support must be positively injurious. Far from the keels being straight, they were in many instances bent considerably, sometimes to the extent of 4 or 5 inches, that bending being the result of a settlement of the wooden or iron structure, and if, when being docked, the curved keel were compelled to settle down on a level and rigid support, it would be suddenly forced back into a straight line, an action which could not fail to set up most destructive strains. On the other hand, on a properly constructed slipway, the cradle and foundations yielded slightly, and accommodated themselves somewhat to the shape of the vessel. It was for that reason they considered Mr. Bruce Bell was wrong when he advocated a firm and unyielding masonry or concrete foundation, and differed from those speakers who contended that a rigid support was the best. The enclosing of the upper portion of a slip within watertight walls was of course a system only to be adopted in special cases; but it must be remembered, that not only was the amount of enclosing wall much less than that for a dry dock, but the pressures to be resisted both by the walls and by the gates, were also much less; and therefore the cost was comparatively small. The arrangement was adopted not because slipways proper were found to be unsatisfactory for vessels of large size, but to economize length in situations where there was a tide. Mr. Giles had instanced a dry dock constructed at a cost of 20,000*l.*, which would accomplish all that the slipway mentioned in the paper would do. He did not know if Mr. Giles understood that the slipway would accommodate two vessels of 280 feet at one time; but if the dock referred to would do that, there must have been some extraordinary and abnormal circumstances to account for the lowness of cost; and of course under those circumstances, a slipway, if more expensive, would not have been recommended. In relation to the cost of the Philadelphia dock, he could not do better than refer to "The Naval Dry Docks of the United States,"[1] by C. B. Stuart, in which might be found detailed accounts not only of that, but of many similar establishments. Those docks were certainly designed in a most extravagant manner. They consisted of a floating dock, a basin, and slips, and in America were considered at the time as extraordinary triumphs of engineering skill. With regard to the straining of vessels when being placed on the cradle, some such action must take place; but it was obvious from experience that

[1] 2nd edition. 4to. New York, 1852.

Mr. Lightfoot. it was not attended with the slightest damage or injury to the vessel. He might mention the slipways on the Tyne belonging to the Wallsend Slipway Company, the general arrangement of which was shown in the diagrams. There were two ways, placed side by side, and each a little over 1,000 feet long. Since being put to work about nine years ago, nearly nine hundred vessels had been taken up on them without the slightest accident of any kind, the heaviest ship being her Majesty's troopship "Tyne." As additional and important testimony as to the safety and advantage of a slipway, he might perhaps be allowed to quote a few words from a letter he had received from one of the most successful ship-builders of the day, Mr. Charles Mitchell, of Newcastle-on-Tyne, who said: "Speaking generally, I consider a slipway better than a dry dock for all vessels up to 2,400 tons gross register, which represents a screw-steamer about 310 feet long by 36 feet beam, and there is nothing to prevent much larger vessels being slipped, but up to this time it has not been the custom to have stronger slips than corresponds with the above size."

In reference to Mr. Redman's observations, the tonnage and dimensions given in the Paper were those dealt with in actual operation, the tonnage being the gross weight of the vessel itself. In several cases the weight of vessels taken on the Author's slipways had considerably exceeded that for which they were designed. He did not think it was correct to say that the launching of a vessel was one of the crucial epochs of its existence. It appeared to him that the process of launching was as much a matter of course as the putting in of the rivets; accidents in launching were unknown now-a-days, except in a very few instances through gross carelessness. He did not consider that the hauling up of a vessel like the "City of Rome" would present any great difficulty. The question of constructing slipways for the largest vessels was purely a commercial one, and if it could be shown that such an establishment would be likely to pay, he would have no hesitation in carrying it out. The difficulty would be in getting a sufficient number of large vessels to keep the slip fully occupied, as it obviously would be undesirable to use machinery designed for 6,000-ton vessels, for those of only 2,000 tons, excepting in rare cases. This appeared to be the obstacle to the construction of very large slipways. The particulars of wages in hauling up a vessel of 2,500 tons at Penarth were not hypothetical, but taken from a real case, the gross weight of vessel being nearly 2,400 tons. He did not think Mr. Summers's remarks had modified the state-

Mr. Lightfoot. ments made in the Paper respecting Day and Summers's gear. So far, it had only been used in two small slips; and at Ayr, where it was now under construction, the weight of vessel to be dealt with was only 1,200 tons. But even here a 12-inch wire-rope, coiling on a drum of no less than 9 feet diameter, had to be adopted. The arrangement of working with blocks had often been applied, generally with chain, and of course only for small weights. He thought Mr. Summers was wrong in his calculations as to the gearing for 3,000-ton vessels; for instead of a pull of 203 tons being enough, he knew from experience that nearer 400 tons would be required, and therefore the factor of safety would only be about $1\frac{3}{4}$. But the gearing for working such large drums would be so heavy and expensive, that any saving in cost over hydraulic power would certainly disappear long before vessels weighing 3,000 tons were reached, while even for a weight of 1,500 tons he questioned whether the risk of breakage of gearing, failures of wire-rope, and renewal of the same, would be compensated by a reduction of a few hundred pounds in first cost. The hydraulic ram, worked on the Authors' system, only took twenty seconds to fleet instead of three minutes, and therefore the deductions on this head were incorrect; and the same advantages as to speed in hauling up light vessels were gained in hydraulic apparatus as with wire-rope by having the triple-powered arrangement shown in the diagrams.

Mr. Thompson. Mr. John Thompson said his remarks would be mainly directed to answering the objections which had been urged against the system of laying foundations under water for slipways without the use of cofferdams; and by a few illustrations he hoped to show that this could be carried out with perfect efficiency and at moderate cost. The various operations would be understood by reference to Fig. 1. When the portion of the site below low-water had been dredged out to the desired depth, the foundation was made by filling in broken stone of convenient size to near the level of the intended platform, upon which a layer of macadam was placed, bringing the foundation up to the required height. As a guide for accurate execution of this work, a line of piles A, was driven on each side of the foundation, clear of the sides of the timber platform, and to these piles guide-timbers B, were affixed at the required inclination of the slipway, and at the depth of the ends of the straight-edge above it. The foundation was now ready to be dressed off true by divers, who, as they frequently had to work in the dark, were provided with iron-faced straight-edges C, made about the weight of a similar volume of water, so as to be easily moved.

Mr. Thompson. These were long enough to reach across the entire foundation, and to slide underneath the guide-timbers. With these straight-edges the divers were able to dress the macadam face so truly, that in one case of a foundation 360 feet long, it was found, after the platform was finished, that there was only one error of $\frac{3}{10}$ inch. The foundation having been thus completed, guide-piles D (Fig. 2), were driven in pairs, about 50 or 60 feet from each end of the intended platform, near the position in which it was to rest, and the platform, which was completely finished on shore, was launched

FIG. 1.

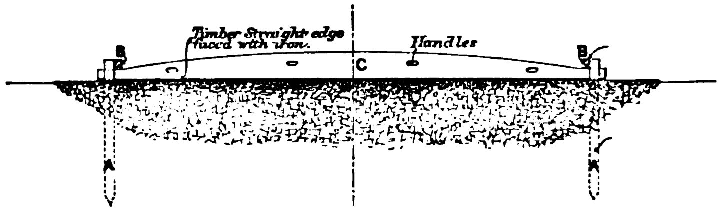
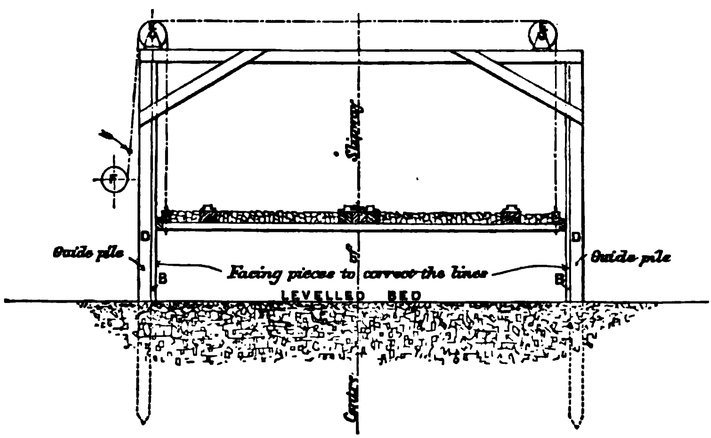


FIG. 2.



like a ship and floated down between the guide-piles. Both the guide-piles D, and the guide-timbers B, were aligned from the shore without difficulty; but in order to obtain complete accuracy, corrected facing-pieces were affixed to the guide-piles, and corresponding facings to the platform itself, so as to bring it in absolute contact with its guides. Chains were then attached to each side of the platform, carried over sheaves E at the tops of the piles, and being brought over to one side of the slipway, were connected together, and then attached to a winch, F, placed on a

barge floating alongside. The scarp joints at the water-line junction were now carefully put into position, and watched to see that they were not displaced during the operation of sinking. Large stones or ballast were now spread evenly over the platform, until there was sufficient weight to sink it, when it was carefully lowered by the winch. In this way any tendency of one side of the platform to sink before the other was prevented, and the platform could be placed in the position intended with certainty and accuracy. In working under water by this system, the expense of divers' work, preparing a foundation for a platform 360 feet long, was about £800; this, however, did not include the cost of slag, nor of the men employed in the barges to convey the slag. Mr. Thompson.

With regard to the statement as to the strain put upon a ship by lifting it with ten or twelve presses off the cradle, he could not conceive how a ship could be much strained by such a process. There would be, no doubt, some strain, but nothing compared to what it was subject to both in launching and in meeting the waves of the ocean. Mr. Giles had spoken of slipways of very large size; but in the Paper, although they were referred to, they were not recommended. In several cases they had recommended their clients not to make slipways for ships of more than 320 feet long and 2,500 tons burden. He might mention the reason for not making such large slipways. As a practical question no doubt they could be made, and would act satisfactorily; but the point was whether there was a sufficient number of ships of, say, 500 feet requiring repairs to render such large slipways profitable. It must be remembered that, although a dock capable of taking a ship of 500 feet could at another tide take two or more ships, so long as their aggregate length did not exceed 500 feet, yet the cradle of a slipway built to take these large vessels could not receive more than one vessel at a tide, however small it might be. In this country, the majority of ships were from 200 to 300 feet long, and the size he had recommended was limited to this, merely to ensure constant employment, without which neither a slipway nor a graving-dock would be profitable in our larger ports. With reference to the slipway at Penarth, the information given in the Paper was obtained about twelve months ago. According to his calculation there was one ship on it every five or six days, and he knew that some ships were on for very extensive repairs. Mr. Giles had put the cost at £50 for each ship; but the charge was not made in that way; it was so much for docking, and so much per ton per tide for rent of the slipway. If a ship went on for extensive

Mr. Thompson. repairs, the cost would be say £10 or £12 for docking, and say 1½d. per ton per day for rent, so that profit was made by rental as well as by docking. As to the straining of a ship by putting it on or launching it off the cradle, taking the inclination of the ways at about 1 in 20, and remembering that the fore end of the cradle was not more than 18 or 20 inches deep, and the after end 6 feet, he did not think that as a rule there would be more strain upon the ship by placing it on the cradle than by putting it into dock where the blocks were level. In a graving-dock the after end touched the blocks first and strained the ship, but so slightly that it had never been recognised; and why there should be anything said of injurious strain when a ship was placed on a cradle he could not understand. The ship was put on, the cradle was hauled up, and no side-blocks were inserted until the after part of the ship touched the blocks. It did not heel over to the one side or the other, and there could not be a straining when that was the case. Notwithstanding the clear explanation of Mr. Summers, Mr. Thompson still saw great difficulty in providing in the gearing sufficient strength to carry the strain upon the rope. It would require a very large drum, and that necessitated so large a spur-wheel and so large a pitch that he thought its use would be attended with great risk.

Correspondence.

Mr. Godfrey. Mr. G. B. Godfrey only last year had completed, for Earle's Shipbuilding and Engineering Company, Limited, at Hull, the largest slipway that had yet been constructed. He referred to its bearing power for taking dead weight, and the hauling power of the engines. The length of the slipway was about the same as that described by the Authors, namely, 860 feet, and having an inclination of 1 in 25. For the foundations he could not agree with the Authors, that mere "surface dressing" was sufficient, excepting where the ground was rock or other hard material. He thought on all softer ground, piling for the whole length was a superior mode of construction, and less subject to settlement, and consequently less costly in maintenance than ordinary excavation and "filling in with suitable material." With piling, and also the method of construction described by the Authors, the whole structure was so bound together, that any settlement or lateral movement was not possible; but, without piling, there must always be a tendency to unequal settlement of the ways, which, he thought, would not be so easily wedged up as the

Authors suggested; and, if at any time overlooked, might cause a severe strain to the ship by the displacement of the cradle when being hauled up. Without piling there was also a tendency to a lateral movement, which might also cause a straining to the ship should the sideways move out of line as the vessel was leaving the water, and her full weight and bearing settling on the cradle. In constructing the slipway for Earle's Company, whole timber piles, cross-sleepers, and longitudinal bearers 13 inches square were used throughout. In the centreway two rows of piles were driven 18 inches apart from centre to centre transversely, and 3 feet from centre to centre longitudinally. For the sideways, single piles were driven 6 feet from centre to centre, these coming opposite every second row of piles in the centreway, thus giving one pile for each lineal foot of slipway, or a supporting power of 10 or 12 tons per lineal foot. A sleeper 30 feet long was placed transversely on the four piles, and one 6 feet long on the two intermediate piles. Upon these sleepers were fixed the longitudinal timbers, or rail bearers, securely fastened with oak trenails. The centre timbers were 4 feet 6 inches wide to take a plate of the same dimensions. The ground for 4 feet below the cross-sleepers was excavated, and filled in with rough chalk for a width of 15 feet on both sides of the slipway; the whole was planked over with 3-inch red-wood deals. A few remarks as to the mode of construction and the method of piling might be of interest. A cofferdam could not be thought of, the situation being exposed, and the sides of the slipway would have required closing by an embankment before one could have been constructed. This would have been too costly. The width of the slipway being 30 feet, a traveller 35 feet wide was constructed to span it transversely; longitudinal timbers were laid on the prepared ground, having ordinary rails fixed upon them. The diameter of the traveller wheels was made to suit the inclination of the slipway. Upon this traveller was placed one of Sisson and White's steam pile-drivers, with 40-feet leaders, and a ram weighing 21 cwt. The formation was partly made ground on the foreshore, and, to obtain the requisite inclination, an average of 10 feet of excavation had to be taken out at low water and carried to the upper portion of the slip, to form the necessary embankment for the slipway, and also for roadways leading from the shipyard. The excavation was first pushed ahead, so as to set the work free for pile-driving, which, when once commenced, was carried on continuously. As the tide ebbed, the pile-driver was allowed to go down upon the traveller by gravitation. The piles were then driven in each

Mr. Godfrey.

Mr. Godfrey. successive row, two and four alternately, the engine being worked across the traveller, from side to side of the slipway, by means of the under pulley and chain. When the tide flowed, the same means were adopted for hauling the traveller and pile-driver above high-water level. The piling was then continued on the upper portion of the slipway until the ebb allowed operations to be again commenced at the lower end. By these means the works were continuously carried on, and the great cost of tidal work was to some extent neutralised. The piles varied from 25 to 50 feet in length, and were driven into the clay until their set for the last blow was $\frac{1}{4}$ inch, with an 8-feet fall of the ram. The work at the lower end of the slip, where the working time was only one half-hour to one hour at lowest spring tides, had to be performed by hand-engines, the piles being of an extra length, and they were subsequently cut off when the tides permitted. The whole of the machinery and cradle was constructed by Earle's Shipbuilding Company, similar in many respects to that described by the Authors, but there were three rams, 15 inches in diameter, so arranged that either one, two, or three might be used, and were supplied by two double-acting pumps, working up to a maximum pressure of 1,250 lbs. per square inch. All parts taking the strain, such as the rods, &c., were of "Siemens-Martin" steel. The slipway and machinery had been so constructed that vessels of from 2,500 to 3,000 tons dead weight might be taken up; but the largest hitherto "slipped" was the "Othello," a Wilson liner, with a length of 316 feet, 36 feet beam, 10 feet 6 inches mean draught, displacing 2,300 tons. The time occupied in slipping vessels varied from half an hour to one hour.

He agreed with the Authors as to the great superiority of this method of hauling ships on slipways, to the old way of disconnecting the links. In proof of this, he might mention that a vessel of 1,200 tons had last week been hauled up in twenty minutes. He further agreed with the Authors that the adoption of slipways or dry docks could only be determined by actual experience of the necessities of different localities. A dry dock had unquestionable advantages when it could be entered from an adjoining wet dock; and, where extensive repairs were required, the machinery could be more easily put into the vessel. On the other hand, for repairs to the lower part of a ship, or the replacing of a screw propeller, a slipway was most favourable, especially in the case of Messrs. Earle's yard, where everything could be brought on trucks alongside the ship on the slipway, either from their workshops or the railway. With reference to the stability of a

slip constructed on the principle he advocated, it was remarked by Sir John Brown, Chairman of Earle's Company, at their last annual meeting, that "After six months' use of the slip, and hauling up some of the largest ships, no settlement whatever had taken place." Mr. Godfrey.

Mr. JAMES LESLIE remarked that in the original Morton's slip, as erected at Dundee in the year 1837, the uppermost chain rod, A (Fig. 3), was 20 feet in length, when it reached the pitch-wheel, the pitch-chain could work no farther. The end B of the pitch-chain was thrown down into the pit, and by means of a block and tackle was hauled up on the other side of the barrel, so that what had been its hinder end became its fore end, and it was ready to work again. That was rather a clumsy and troublesome operation; and, moreover, the fall of the chain Mr. Leslie.

FIG. 3.

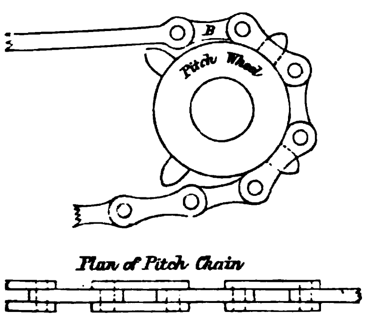
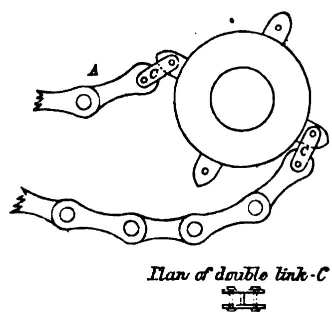


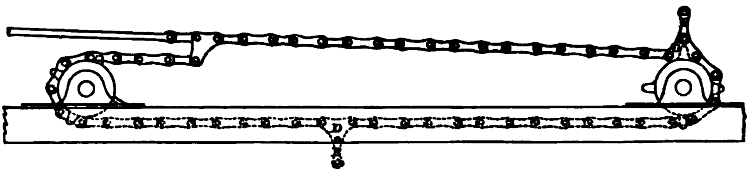
FIG. 4.



smashed the pavement floor of the pit. To obviate this, a small hole was bored in each of the studs of the pitch-wheel, and a small double link, C (Fig. 4), was made with two eyes, and two pins to fit them; one end was pinned through a stud of the pitch-wheel, and one through the eye of the chain B (Fig. 3), the engine set on, and one turn of the pitch-wheel carried the end of the chain round the pitch-wheel to its proper place, as at A (Fig. 4), reversed and ready to work again. Within a year or two afterwards, with the view of dispensing with the reversing of the pitch-chain, he made some sketches of an endless pitch-chain, which he wished applied to the Dundee slip; but, from the buildings and machinery being all completed, it was found that the expense would be too great, and the idea was given up. In 1849, he made for the Pacific Steam Navigation Company plans and specifications of a slip, proposed to be laid down at San Lorenzo, with an endless

Mr. Leslie. chain. That slip was never made; but in 1851 the endless chain was, with his concurrence, adopted by Messrs. Morton for the Duke of Buccleuch's slip at Granton. That slip had an endless pitch-chain 60 feet in length, with three hump-backed links, D (Fig. 5), in its length, having each three eyes, one on the back

FIG. 5.



with a common single link, E, attached for coupling the uppermost chain rod. Fig. 5 would explain the action without farther description, but there required to be a shift or fleeting of rods every 20 feet, instead of every 40 feet when two rods were taken out at once. The Granton slip had worked satisfactorily ever since, and up to 1857 the endless pitch-chain had been adopted at Hobart Town, Trieste, and Newcastle; but since then a hydraulic purchase had been sometimes used instead of the pitch-chain machinery; and he understood from Messrs. Morton that in some cases, instead of a pitch-chain, they used two chain cables working over two pitch wheels; meaning thereby, he presumed, wheels with indents for the sideway links sunk in their periphery.

Mr. Taylor. Mr. JAMES TAYLOR, of Birkenhead, thought it was possible, without winding-barrels being stationary, to arrange a system of grooved pulley-heads, geared to work together in unison with steel wire-ropes passing and crossing round double heads without chafing, the ends being anchored at the top and bottom of the incline. The system should be actuated by means of a pair of engines having link reversing-motion, with boiler upon a travelling platform attached to the upper end of the cradle, to travel up or down the incline at will, thus producing a continuous haul from the start to the end of the journeys of the cradle.

Mr. Tweddell. Mr. R. H. TWEDDELL considered that the Paper had been brought before the Institution at a very appropriate time. The building of new ships was proceeding at a rate hitherto unexampled; it was, therefore, evident that ready and economical means of repairing and maintaining these vessels must be provided in a similar ratio. When such repairs required that the vessel be left high and dry, it was an important matter to reduce the cost of so heavy an undertaking. He should like to ask what was the relative cost of pumping out a graving dock, in order to admit a

vessel, and of drawing up a vessel on to a slipway, assuming the repairing capacities per annum to be equal; also, the relative cost of the mechanical appliances in each case. In the graving-dock there would be the pumping apparatus as against the hauling apparatus in the other. The cost of cradles might be put against that of gates or caisson, leaving the cost of masonry foundations, &c., out of the question, as these varied greatly in different cases. While a slipway undoubtedly presented some advantages in allowing easy and early access for painting and drying, he should imagine that a graving-dock would be the best for such extensive repairs as lifting out boilers or engines, since sheer-legs could more easily command the vessel in this case, although, of course, sheer-legs were now very often conveniently placed near slipways. He should like, also, to ask whether there was any difference, as a rule, in the rate per ton for repairing a vessel on a slipway or in a graving-dock. This question would arise in cases where the owners of the slipway or dock did not undertake the repairs. In comparing the relative merits of slipways and graving-docks, it had been asked if, in the case of a certain slipway, the dividends were not due to the profits arising from the repairs done on the slipway, since a slipway was only to enable repairs to be effected. He saw no objection to any profits thus made being placed to the credit of the slipway as an undertaking, or to a graving-dock either. He thought the use of an accumulator was almost essential, not only on account of the safety and speed thus obtained, but also because it could then be made available for working hydraulic machine-tools, for punching, riveting, &c. One of his own machines was being thus worked at a slipway fitted up by the Authors of the Paper. The fact of having an accumulator would also allow of the working of hydraulic capstans or large sheers on adjacent wharfs, and would enable the engines to be taken out or put into the vessel before or after going on to the slipway. The Authors' improvements for avoiding "fleeting" were very effective and neat, but their cost would, he should think, be greater than Sir W. Armstrong's system of using a chain dropping into a pit. In reference to Messrs. Day and Summers's system, would not the objections raised by the Authors be met by the use of three or four separate hauling-drums? Mr. Tweddell.

Mr. T. B. Lightfoot, in reply to the correspondence, observed, in reference to the suggestion that the foundations adopted in a slipway recently constructed by Earle's Shipbuilding and Engineering Company, Limited, would be less costly in maintenance than if constructed by the method mentioned in the Paper, that Mr. Lightfoot.

Mr. Lightfoot. no doubt in some instances this might be so; but at Penarth the expenditure on the ways had been so trifling since operations had been commenced in 1879, that whatever might have been the case at Messrs. Earle's, it was evident the foundations at Penarth had given most ample support. Mere surface-dressing and filling had not been recommended in the Paper in every case, but it had been distinctly stated that piling was sometimes required; and probably at Messrs. Earle's the Authors would have pursued the same course as Mr. Godfrey. With regard to the machinery, Messrs. Earle had adopted the system introduced by the Authors, and they were glad to learn it had given such satisfaction. The hauling arrangement referred to by Mr. Taylor, had been considered by the Authors, both in connection with steam and hydraulic power; but they did not think it a desirable plan to adopt. The work done in hauling a ship of 2,500 tons burden on to a slip would be about 170,000 foot-tons including friction: while to empty a graving-dock, capable of accommodating two vessels at a time, about 34,300 tons of water would have to be raised an average height of, say, 15 feet, equivalent to an expenditure of 515,000 foot-tons every time a vessel was admitted. Sir W. G. Armstrong and Co. had only used chains for hauling up the cradle and load in the case of two small slips for dredgers and hopper barges, and such an apparatus was inapplicable for dealing with vessels weighing 2,500 tons. In any case the cost would fully equal, if not exceed, that of the appliances recommended in the Paper.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 1852.*)

"Economical River-Training in India."

By CARLETON FOWELL TUFNELL, Assoc. M. Inst. C.E.

ONE of the most striking natural features of Northern India is the condition of its rivers, or what during nine months of the year can only by courtesy be termed rivers. The traveller who suddenly finds himself face to face with a bridge ½ mile in length, carrying a road over an arid waste, studded here and there with small ponds and patches of rich vegetation, cannot but wonder at the unnecessarily lavish expenditure, as he would term it, of the Indian Public Works Department. Let the traveller, however, find himself at the same spot during the monsoon, when through every span a foaming torrent rushes, and the reason for the construction of the bridge is at once apparent. To the engineer, responsible for the safe keeping of the bridges and of the villages near the river banks, this characteristic is invaluable, enabling him to work dry-shod in making preparations to deal with the annually recurring floods. The regularity with which the monsoon visits India is another source of comfort to the custodian, who knows exactly when to have protective measures perfected.

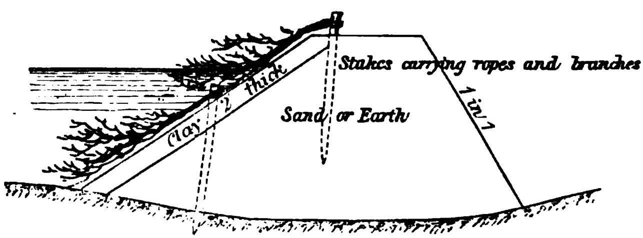
The methods of training streams by force vary in different localities according to requirements and natural resources. Where the river-bed contains boulders, these are massed together, and spurs of immense strength are readily constructed. Such rivers, however, require but slight attention as compared with those whose beds are entirely of sand, and which change their course on the least provocation. When block kunkur is at hand, or easily obtainable, spurs of great solidity are easily formed. This method of protection obtains on the Scinde, Punjab, and Delhi Railway over the rivers discussed later in this Paper, which pass under the line a few miles above the actual points to be considered. The kunkur is brought in the company's trucks, and discharged near the abutments of the various bridges. Earth, or even sand with a

facing of tree branches (Fig. 1), has been found to act efficiently where the cost of carriage of boulders or kunkur has rendered the more solid spurs impracticable. Spurs of this description were, in fact, in almost universal use until of late years in Northern India, and are still from time to time adopted.

Artificial sandbanks of huge dimensions have also been tried without tree-facing; but labour, the sole item of expenditure in such works, has now become so expensive that the reduction in size, rendered possible when a facing of clay and tree branches was tried, has more than counteracted the extra cost of the facing. Only where trees are exceedingly scarce, therefore, is it wise to adopt this plan.

The object of this Paper is, however, mainly to consider the subject of river-training where coaxing, as opposed to force, is the primary agent, an agent prompted in the first instance no doubt

Fig. 1.

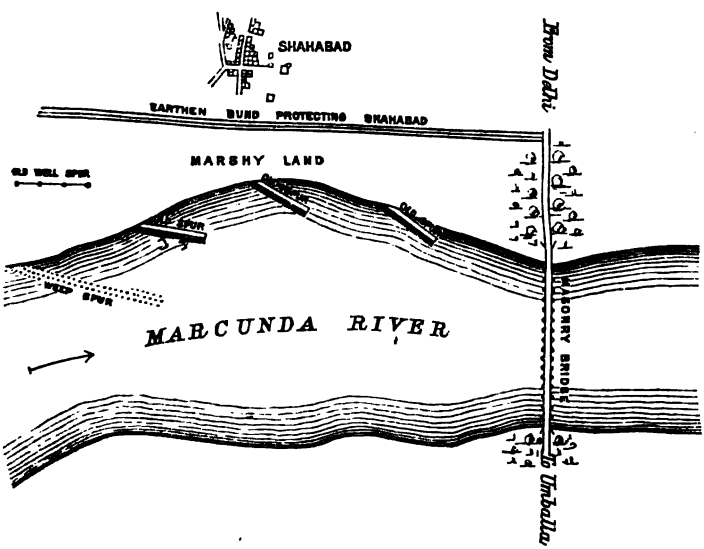


by economy. So vacillating are Indian rivers, so changeable their streams from day to day, that it is often absolutely necessary to prepare precautionary traps and stumbling-blocks in places comparatively remote from the river bank. The construction of strong spurs not only necessitates money but time, and, when complete, these cannot fail to produce a galling effect on the holder of the government purse-strings; especially if, by chance, the spurs have no work to perform, and are left high and dry.

To better describe the use of floating-spurs, Brownlow's weeds, &c., it is thought advisable to take three actual examples of rivers lately under the charge of the Author. Figs. 2, 3 and 4 show three rivers at points where they are crossed by the Grand Trunk Road. Over the Marcunda (Fig. 2) a brick bridge of twenty-seven spans of 36½ feet each carries the road, whilst, as regards the Tangri and Oomla, the construction of the Scinde, Punjab, and Delhi Railway has so reduced the traffic on the Grand Trunk Road in this part of late years, that funds have not been provided for

bridging these smaller rivers (Figs. 3 and 4). During the dry months a temporary road of serbunda grass (a coarse rush) is usually laid down and replenished from time to time; whilst in floods an elephant is kept at hand for the use of travellers, all cart-traffic being for the time suspended. Another method of crossing is largely practised by the native drovers and others. Herds of cattle swim and reswim the torrents daily, starting up-stream far above the intended place of landing. By clutching the tails of the fatter kine the natives effect a safe passage, a feat which would be impossible but for the aid thus afforded. The three rivers to be discussed run parallel to each other towards the

FIG. 2.



west, and all three cross the road within 12 miles of Umballa, and at a distance of about 30 miles from the lower Himalayan ranges.

The river Marcunda, at the point in question, is about 1,600 feet in breadth, and there is an entire absence of flowing water during the greater portion of the year. In the rains the depth, which at times and in places reaches as much as 15 feet, varies hourly according to the volume of water and to the ever-changing form of channel bed. Till within the last few years, the full force of the stream was principally felt on the northern shore, but an entire

change has since taken place, and protective measures are now needed on the southern bank alone.

Fig. 3.

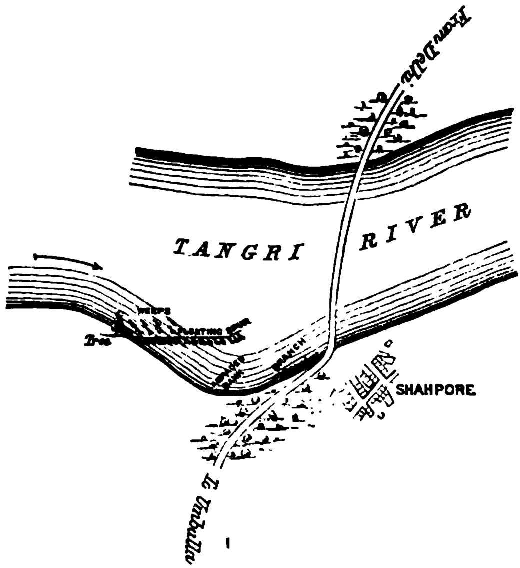
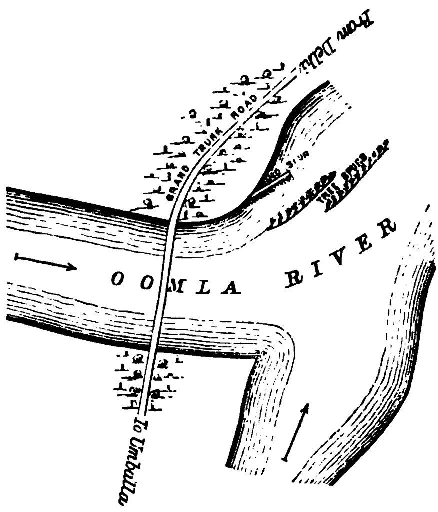


Fig. 4.

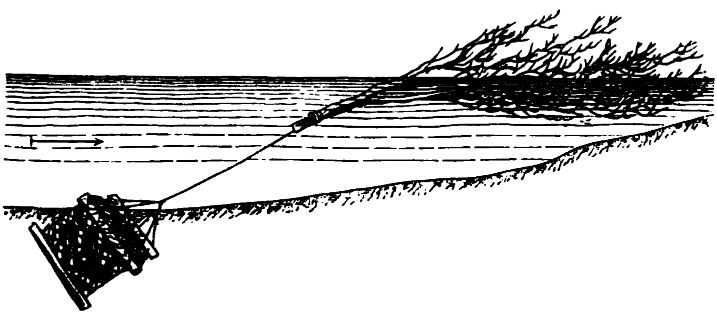


Beyond an immense earthen bund or spur, about 2 miles in length (Fig. 2), is situated the native city of Shahabad. The city

is practically protected by this bund; moreover, any considerable incursion of the river in that direction would be resisted, owing to the danger it would entail on the southern abutment of the Marcunda bridge.

The commencement, then, of the monsoon of 1880 saw the main stream on the southern shore, where it was opposed by three strong earthen spurs faced with the branches, as shown in Fig. 1. These spurs had been severely injured during the previous year, and would have required a large expenditure to render them efficient. Instead of undertaking the extensive repairs of earthwork necessary, and replenishing the facing of branches, a plan was adopted to induce the stream to change its course, by causing a deposit of silt over the abraded face of the spur which was first exposed to the stream. This plan consisted in firmly attaching two long "monj" ropes, 5 inches in

Fig. 5.



diameter, to the top of the bund at selected spots, and anchoring the other ends in the river-bed by means of crates filled with bricks, and buried beneath the sand. To the ropes were attached, by means of ban string, and as close together as possible, large branches as bushy as procurable. This spur was covered, so to speak, by a second spur, composed entirely of Brownlow's weeds, situated a short distance up stream (Fig. 2). The weeds (Fig. 5) were placed at intervals of 20 feet in two rows, likewise 20 feet apart. Rough timbers about 3½ feet in length and 3 inches in average diameter, were first firmly nailed and lashed together to form a cubical crate; around these stout cords were intertwined, forming a network for containing brickbats. Old kilns, used during the construction of the bridge, afforded ample bricks. The crates were first sunk in position in the sand, care being taken to expose a flat surface at right angles to the force exerted by the tree when floated. The rope connecting the tree and the anchor

measured 2½ inches in diameter and about 12 feet in length, whilst the tree was selected of a large size, and thick, bushy nature. The entire spur contained one hundred of these weeds, and extended about 800 feet in the river-bed at an angle of 30° with the direction of the stream. Additional strength was given to the spur at both extremities by increasing the rows from two to three for short distances. The effect of this spur was satisfactory. At the close of the rainy season no vestige of the hindermost row of weeds was discernible, so well had the front row done its work. Over the entire bed in rear of the spur sand had accumulated to a height of several feet, and the main stream was diverted into the middle of the channel.

Before dismissing the subject of the Marcunda defence-works, some mention should be made of a spur which now stands high and dry, far away from the present watercourse, and which affords an example of the application of force to river-training. The position of this spur is shown in Fig. 2. A series of enormous brick wells, distant about 50 feet apart, and sunk, it is believed, 25 feet, are connected by a heavy iron chain, which is rigidly anchored within the wells. It is probable that earthen bunds extended from well to well, the iron chain carrying a facing of tree branches. No trace is left of the earthwork, and the chains and wells are scarcely perceptible, being almost entirely covered by sand and vegetation.

Yearly encroachments on the road, and increasing danger to the village of Shahpore by the Tangri (Fig. 3), rendered it a matter of the utmost importance to perfect defensive measures at this point before the rains of 1880. Earthen spurs, of the type shown in Fig. 1, with Brownlow's weeds at the toe, were first constructed; but an almost unprecedented flood early in the monsoon completely removed all vestige of the spurs and weeds. The following method was thereupon adopted. The perpendicular banks, cut away by the flood immediately on the upstream side of the road, were first sloped off; stakes were then firmly planted above, and the arrangement of "branch-facing" was tried, as though the natural bank were itself a spur. At the foot, crates of brickbats were loosely thrown. Advantage was taken of a large tree on the bank, Fig. 3, to throw out a floating spur. A 5-inch rope was attached to the tree and carried into the stream at an angle of about 40° to the bank for a distance of 200 feet, where it was finally anchored with great care by numerous crates, &c. To this rope branches were closely tied, and at intervals of 5 feet large balks of deodar wood (procured from an old bridge in the neigh-

bourhood) were attached in order to aid flotation. Brownlow's weeds were also distributed above the spur to help its action. A sudden subsidence of the water, after the flood alluded to, enabled this work to be effectually carried out, and the result was all that could be wished, the main stream being at once diverted into mid-channel.

The plan adopted in the case of the river Oomla is shown in Figs. 4, 6 and 7. Large trunks of trees, about 12 inches in

Fig. 6.

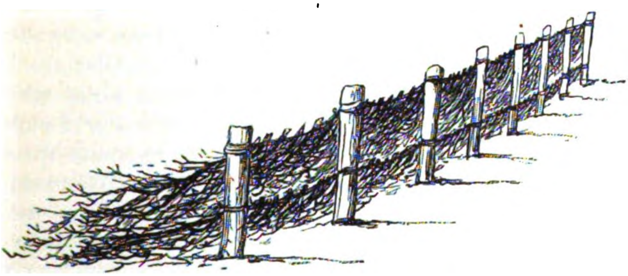
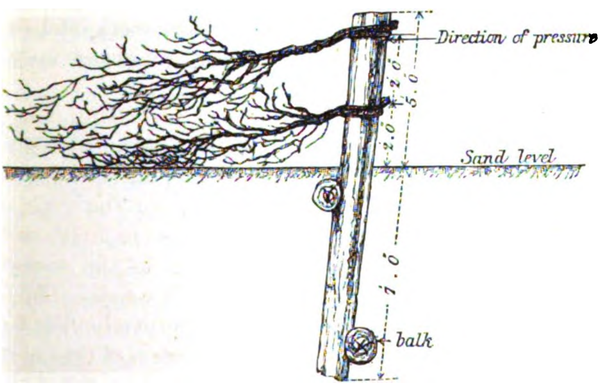


Fig. 7.



diameter and 12 feet in length, were sunk to a depth of 7 feet in the sand at distances of 12 feet apart. It was at first intended to sink them by sharpening the butt-end and "jumping" them, but it was found more expeditious to dig a deep hole and thus let them in. Extra resistance was opposed to the pressure of the stream by placing large balks 4 to 5 feet long, as shown in Fig. 7. From tree to tree were attached two 5-inch ropes, respectively 2 feet and 4 feet above the ground; to these were tied, as closely together as possible, large bushy branches on the side

furthest from the stream. A few Brownlow's weeds were placed at the down-stream extremity of the spurs, as an extra incentive to the current to cause an accumulation of silt. The abnormally high flood, which so greatly damaged the Tangri banks, also sorely tried the tree spurs on the Oomla; at the close of the monsoon, however, a decided change in the river-bed was perceptible.

That the cost of spurs, as above described, is but trifling compared with that of kunkur or earthen embankments sufficiently massive to ensure safe resistance to heavy floods, will readily be allowed, unless indeed in the event of trees being almost unprocurable. In the cases under discussion the trees were obtained from plantations along the Grand Trunk Road, whilst the brickbats were brought from abandoned Government kilns, which in each instance were close at hand. The cost of rope and nails was practically nothing, and the unskilled labour requisite amounted to a mere bagatelle compared with the carriage. Where carriage entails so large a proportion of expenditure, it is impossible to enter minutely into the question of rates, which practically vary for every spur. Suffice it to say that, under advantageous circumstances, a Brownlow's weed would cost from 2 rupees (4*s.*) to 3 rupees 8 annas complete, and in position, whilst for trees felled and fixed (as in the Oomla spur) 1 rupee each was sufficient. The cost of branches per lineal foot, including rope and string, was from 4 annas to 8 annas (6*d.* to 1*s.*).

The Paper is illustrated by several diagrams, from which the woodcuts in the text have been prepared.

(*Paper No. 1887.*)

"The Iquique Railway, Southern Peru."

By Henry Sadleir Ridings, M.A., M. Inst. C.E.

The elevated plain of the province of Tarapaca is connected by rail with three ports on the Pacific Ocean, namely, Iquique, Pisagua, and Patillos. The present Paper refers chiefly to the Iquique Railway, in latitude 20° 13′ S.; longitude, 70° 13′ W. The object of the railways was to develop the nitrate of soda trade, and much has been effected towards this end. Between 1870 and 1879 the quantity of nitrate annually exported, from all the ports of the province, was 5,000,000 quintals, or 227,272 tons, whereas the present quantity is about 340,909 tons annually, of which nearly 320,000 tons pass over the railways.

The abruptness of the mountains facing the sea, and their rugged and broken character, entailed considerable difficulty in finding the best line, and many trial sections had to be taken. On the Pisagua line it was necessary to put in no less than three reversing sidings, but at Iquique one was sufficient. This was protected by a safety siding, running up at gradients gradually increasing to a maximum of 7 in 100. The cuttings were mostly in hard metamorphic rocks, and the difficulties of construction were much increased from the barrenness of the soil and the absence of potable water. Provisions and water, distilled from sea-water, had to be carried by mules over the mountains.

The Iquique Railway, including branches and sidings to factories, is 93 miles long. To a point 3,067 feet above sea-level, and distant from the port 19 miles, there is a continuous rise, the average gradient being 3·06 per 100, and the maximum 4 per 100. After this point there are alternating lengths of level, and rising and falling gradients, the former being 3 per 100, and the latter 1·7, 2·16, and 3 per 100; so that leaving the nitrate grounds for the port, the last-named gradients are against the heavy traffic. The curves from the port, to the height of 3,067 feet, are numerous, and range from 1,000 feet radius to a minimum of 350 feet. The permanent way, 4 feet 8½ inches gauge, is laid with

steel rails of the Vignoles type, of 64 lbs. to the lineal yard, and tie-rods are freely adopted on the curves.

Three classes of locomotives are in use; those of Sharp, Stewart, and Co.; Rogers (American); and the Fairlie. The mileage of the different classes for the summer, October 1881 to March 1882 inclusive, was:—Rogers, 11,616; Sharp, Stewart, and Co., 25,269; and Fairlie, 57,517; which, with 4,439 run, for a short time, by another type of locomotive, brings the total for six months to 98,841 miles.

Platform wagons, with eight wheels on two bogie-frames, have been adopted with a brake acting on each wheel. Some of the wheels are of chilled cast iron; while others, with radial spokes, have steel tires. Although the life of the former in the United States is upwards of 100,000 miles, their use on a mountain railway like this, where skidding cannot always be avoided, produces great wear and tear, through the flat places that are created in the tread, which it is impossible to turn up.

Two classes of passenger-coach are employed; the American, on two four-wheeled bogie frames, and the Grover carriage. Both pass the curves with ease and safety.

In the period under review, the paying weight moved over the railway was as follows:—

	From the Port.	To the Port.
1881.—October	4,957 tons.	14,942 tons.
November	5,020 „	18,224 „
December	5,161 „	20,363 „
1882.—January	5,478 „	20,576 „
February	5,940 „	17,119 „
March	6,013 „	19,577 „
Totals	32,569 „	110,801 „

This weight is exclusive of small traffic, materials for extensions, stores, &c. The dead weight required for the removal of the traffic from the port consisted of two thousand four hundred and twenty-eight wagons, each weighing 7 tons, and the number of vehicles which left the port empty was six thousand and forty. Therefore the total weight hauled against an average gradient of 3·06 per cent., for a distance of 19 miles, has been:—

	Tons.
Paying load	32,569
Wagons which contained paying load	16,966
6,040 empty vehicles	42,280
Total	91,815

A loaded wagon weighs 20 tons, of which 7 tons constitute the non-paying weight. At times some of the wagons to the port have been loaded with 15 tons, which the Author considers excessive; also some of the first type of platform wagons tared rather over 7 tons. This undue proportion of dead to paying load will be remedied on the introduction of new rolling stock; for, admirable as the double bogie car is for passing sharp curves, a lighter vehicle is far more suitable to a road on which there are such steep gradients as on this. In the movement of the total paying-load, or 143,370 tons, the number of vehicles employed was two hundred and twenty-four. The mileage by loaded vehicles during the six months was in the proportion of 2·166 to 1, or 439,627 miles loaded to 202,947 empty.

During the period referred to, 8,484,536 gallons of water were consumed by the locomotives, or 1,414,089 gallons per month, which, at the price of 1½ cent., at the exchange of 35*d.* is £3,093 6*s.* 4*d.* On the mileage of 98,841 the running has consequently been 11·65 miles per 1,000 gallons of water consumed.

Three classes of water are used; that which is brought in steamboats from the wells of Arica, 100 miles north of Iquique; that which is found in the wells on the plains, about 45 miles from the port, and conveyed over some parts of the system in tanks, and by pipes over others; and distilled sea-water. The water from Arica is used in its natural state; that from the plains of Tarapaca is prepared, before using it in the locomotive boilers, by precipitating the magnesia and lime in solution by carbonate of soda and quicklime. The Arica water is the best suited to the boilers.

The following is an analysis, in grams, of impurities to a litre of water:—

—	From Wells on the Plains, natural state.	From Wells on the Plains, prepared by precipitation.	From Arica.
	Gram.	Gram.	Gram.
Common salt	1·5799	1·9568	0·2447
Chloride of magnesia	0·1737	..	..
Sulphate of soda	0·0735	1·5847	0·1397
Sulphate of lime	0·9843	..	0·1931
Carbonate of lime	0·2499	0·0800	0·1100
Carbonate of magnesia	0·0323	0·0306	0·0080
Silica	0·0200	0·0180	0·0300
	3·1136	3·6701	0·7255

The quality of the water is not the only difficulty to be contended

with, as, in consequence of the want of a line of pipes connecting the wells of the plains with the stations, it has been necessary to convey the water in tanks to several points where the locomotives stop, and to make use, therefore, of the steam power in the haulage of tanks, instead of a more paying load. For some years, too, it was necessary to propel the tanks in ascending the gradient, in order to receive their water into the tanks of the locomotives through a pipe which connected them with the latter.

The unsettled state of the country has hitherto militated much against the improvement of the property. Another element which greatly increases the cost of working is the dense fog, especially during winter, which produces the slippery rail so common in mountainous districts. At this season the tires of the locomotives suffer very much, their average life being 32,000 miles.

The mileage of the locomotives during the period referred to has been 98,841; the coal consumed at the rate of 1 ton for each 29 miles; and the cost of maintenance of the permanent way has been, for wages and materials, \$68,307·66, or \$734·49 per mile. The cost of maintenance per mile run has been \$0·69, at 35*d.* exchange, and \$0·47 for each ton carried. The average distance travelled by 1 ton is 38 miles, and the cost of maintenance per ton per mile has been 1¼ cent. The total working expenses during the six months referred to were 45·399 per cent. of the gross receipts.

On no part of the system is the speed allowed to exceed 15 miles an hour, and in the descent of the steep gradients it is reduced to 8 miles. The movement of the trains is conducted on the permissive-block system, and, since the line has been under English management, immunity from accident has placed it on a very favourable footing as compared with other railways.

Some of the special features of the railways of Southern Peru, and the peculiar difficulties encountered in the construction and working of them, are the following. The great height to be attained, between 3,000 and 4,000 feet above sea-level, within practically narrow limits of distance, necessitated very steep gradients, commencing at the ports of Iquique and Pisagua, as the mountains rise abruptly from the sea. The extremely rugged and broken character of the country for a considerable distance after the coast-range is surmounted, necessitated many trial surveys and rectifications before the line was finally decided upon, and made the use of very sharp curves obligatory to avoid enormous expense. On this section also the cuttings were all either in solid rock, or in the baked crust, which was so hard that powder had to

be used. The entire absence of potable water and of food products was a serious difficulty, and a source of great expense during construction, all the water used at that time being distilled, and the food brought in steamers from more favoured parts. As shown above, the water difficulty has been partially overcome, and by the expenditure of more capital, a first-rate supply may be obtained from the second range of mountains to the east of Iquique. Severe earthquakes, followed nearly always by inrushings of the sea, have been a serious difficulty and a source of expense. That of the 9th of May, 1877, occurring as it did at night, and without warning, involved a direct outlay (for materials and wages) of $17,000 on the Iquique section, and a rather smaller, but still considerable expense, on the Pisagua section; and the loss from suspension of traffic during repairs was of course much more serious. On that occasion the town line, used for taking the nitrate of soda to the various stores and wharves along the sea-shore, was destroyed, and in some places completely obliterated; the railway pier also was washed away, and the water-condensers were much injured. Up the mountain the rails were in many places twisted in a most extraordinary manner; embankments were shaken down, leaving the rails suspended in the air, and rocks were thrown into the cuttings. Large gangs of men were set to work, and in a comparatively short time repaired the damage.

Serious conflagrations have twice destroyed the most important business portion of the town of Iquique, disturbing the railway traffic for a short time, though this loss has been more than made up for shortly afterwards by the increased demand for nitrate from the interior to supply the place of that burned.

The railways seem now to have entered upon a period of prosperity; but for some years previously the war between Chili and Peru was a cause of great loss, both from destruction of property by bombardments, &c., and from the injury to the traffic, sometimes from blockading the ports, and at other times from the forced use of the lines for the carriage of troops and war-material, and the compulsory lowering of rates. For a considerable period the erecting and repairing shops were completely dismantled, and the pieces of the machinery, &c., buried.

(*Paper No. 1894.*)

"Weights of Structures estimated Graphically."

By JOSEPH HAYWOOD WATSON BUCK, M. Inst. C.E.

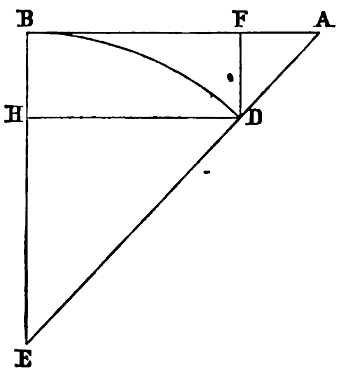
As the graphic method of ascertaining the strains produced on structures of different kinds, by the application of weight, is now deservedly attracting considerable attention, it has occurred to the Author that it might be interesting, and not devoid of practical utility, to endeavour to ascertain to what extent a similar system can be employed in estimating the weights of the structures themselves, in such cases as framed girders, roofs, &c.

The weight of such a structure adapted to carry a distributed fixed load, in addition to its own weight, may be considered as represented by the expression $\frac{W Q}{1 - Q}$, where W is the weight carried, and $W Q$ the weight of structure required to carry W alone, or $\frac{W a}{W - a}$, where $a = W Q$.

These premises having been stated, the Author will show how these formulas, as applied to different types of structure, may be represented by straight lines, and thus the result be obtained simply by scale measurement.

Let B D (Fig. 1) be the arc of a circle, of which B E is the radius, H D the sine, B A the tangent, and E A the secant.

FIG. 1.



Draw F D parallel to B H, intersecting B A in the point F.

Then, by similar triangles, $HE : ED :: FD : DA$, and therefore $DA = \frac{ED \times FD}{HE}$; but $HE = BE - BH$; $ED = BE$, and $FD = BH$.

Therefore $$DA = \frac{BE \times BH}{BE - BH}.$$

That is to say, DA may be considered as representing the weight of a girder of unknown span carrying the weight BE and its own weight in addition, and BH represents the proportion of the total weight DA due simply to the weight BE; for if $BE = W$, and $BH = a$, the formula becomes $DA = \frac{W a}{W - a}$ as before. Again, if $BE = 1, BH = \frac{a}{W}$ or Q, and therefore $DA = \frac{Q}{1 - Q}$, or the former value divided by W, that is, the proportion of the total weight of the structure necessary to support a unit of load and its own weight in addition; consequently if the load be again represented by W, the total weight of the structure becomes $\frac{W Q}{1 - Q}$, as before; which, in fact, is the system adopted in the use of tabular sines, &c., where radius = 1, and where, in consequence, a multiplier W has to be used when radius = W.

The conclusion arrived at is, that if the weight W carried by the structure = radius, and the weight of structure necessary to carry W alone = versed sine to radius W; then the weight of structure required to carry W and its own weight in addition,

= (secant to radius W) − (radius W), or W (tabular sec. − 1).

Fig. 2.

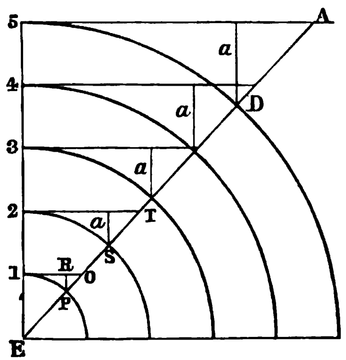


Fig. 2, showing five concentric circles, whose radii respectively

represent the weights 1, 2, 3, 4, 5, further elucidates the subject. Let D A be the weight of a girder of known span, capable of carrying the weight 5, and its own weight in addition,

$$\text{D A} = \frac{5 \times a}{5 - a} = 5 \text{ times } \frac{1 \times \text{R P}}{1 - \text{R P}},$$

but
$$\text{R P} = \frac{a}{5} = \text{Q}.$$

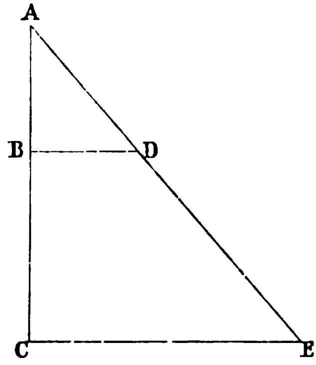
Therefore
$$\text{D A} = 5 \times \frac{\text{Q}}{1 - \text{Q}}.$$

Also P O represents the weight of a girder of the same span and general proportions as that the weight of which is represented by D A, but carrying 1 instead of 5; S T represents the weight of such a girder carrying 2, and so on.

If, now, a graphic method be found of ascertaining the value of a or Q for any other span of the same description of structure, all the elements will exist necessary for expressing graphically the weight of any other structure of the same type, with any load and span.

In the case of solid beams carrying both a fixed and a moving load, when the same factor of safety is allowed to each, and the proportion of depth to span remains constant, Q varies as the span; or, in other words, the weight of beam required to carry the whole external load alone, varies as the span when the load remains constant. It will be convenient, and sufficiently accurate for the present purpose, to proceed on this assumption in every case.

FIG. 3.

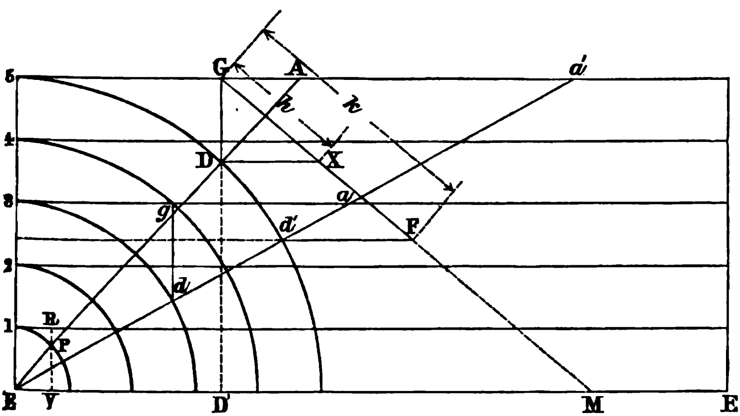


Let A B = a (Fig. 3) for a girder of which the span = h; and let A C = a for a girder of the same description, of which the

span = k; then $h : k :: \mathrm{A\,B} : \mathrm{A\,C}$, and therefore $\mathrm{A\,C} = \frac{\mathrm{A\,B} \times k}{h}$, obtained graphically thus. Place any convenient drawing scale in the position shown by the line A D E, with zero at A, making A D = the span h, and A E = the span k to that scale. Join B D, and parallel to it draw E C, intersecting A C in the point C. It is evident that the required proportion A D : A E :: A B : A C exists, whatever scale is used for measuring the distances A D and A E, and it would therefore hold good if those lines were drawn to the same scale as A B and A C, that is, $h : k :: \mathrm{A\,B} : \mathrm{A\,C}$, and therefore $\mathrm{A\,C} = \frac{\mathrm{A\,B} \times k}{h}$, the required length.

The application of this principle to Fig. 2 is shown in Fig. 4. Let D A = the weight of a given girder of the span h, carrying 5

FIG. 4.



and let it be required to find the weight of a girder of the same description of the span k, carrying 3. From the point D draw the line D X parallel to the tangents, and, with any convenient scale, set off the distance G X = h, intersecting D X in X, also making G F = k; from the point F draw F d' parallel to the tangents, intersecting the circle with radius 5 in d'. Through the point d' draw the radiating line E d' a', then d' a' is the weight of the girder with the span k carrying 5, and $d\,a$ is the weight of the girder with the span k carrying 3. The procedure would be similar if k were the span of the given girder. If there were no data, the weight of a girder of the span k, of the strength required to carry 3 alone, would have to be estimated in the usual way.

This would be represented by $g\,d$, and $d\,a$ would give the total weight of the girder as before.

It is now to be observed that in the formulas at the commencement of this Paper the limiting span is reached when Q = 1, or when a = W, that is, the span being proportional to a, or versed sine, it reaches its limit when the versed sine becomes equal to the radius, or, in other words, when (secant − radius) the total weight of the girder is infinite, and the result is immediately obtained in the diagram by producing G F to meet E E′ in the point M, for if G D be also produced to meet E E′ in D′, G D : G X : : G D′ : G M; but G X is the span when G D = a, therefore G M is the span when G D′ = a, but G D′ = 5 = W; therefore G M is the span when a = W, or the limiting span. But when G D′ = a, R V = Q; and R V = 1, therefore G M is the span when Q = 1, or the limiting span.

When the external load is proportional to the span, as in the case of most bridges, and of roofs having principals the same distance apart in each instance,

$$W = (\text{weight per lineal foot on given structure}) \times (\text{span of proposed structure in feet});$$

and the results obtained under these conditions are the most accurate: but it must be observed that in the case of roofs, unless an adequate weight be adopted in each instance to represent the weight of snow and the equivalent of the wind-pressure, and added to the weight of covering, the resulting limiting span will be too low, and the weight of principal obtained by the diagram will be too high, as it will be obtained by applying the (sec. − rad.) of the circle whose radius = (weight of covering + weight of snow + equivalent of wind-pressure), to the circle whose radius = weight of covering only, which is the same thing as using too large a scale, causing the radiating lines to form a less angle than they should with the horizontal line E E′ (Fig. 4). Also, when a greater or less load per lineal foot of principal is carried, owing to the principals being farther apart or closer than in the case of the given structure, the proportion of wind-pressure, to the total external load will not remain the same, as that portion of the covering consisting of cross-girders may be considered to vary per lineal foot of principal as the square of the distance between the principals; and the remainder of the covering, including the weight of snow and the equivalent of the wind-pressure, to vary per lineal foot simply as the distance between the principals, though, strictly speaking, the wind-pressure and dead load should

not be combined. This combination, however, is useful and fairly accurate when an actual equivalent in respect of the resultant weight of structure is adopted in the given roof instead of what may be termed an average vertical component per lineal foot of principal; but this is merely accidental, and entirely dependent on practical considerations, and the Author believes that its tendency is to slightly under-estimate the weights of smaller roofs than the sample one. The necessary allowance for wind-pressure must therefore, in the Author's opinion, to some extent rest on experience.

Of course, having by these means estimated the weight of any structure, the cubical content in feet can be obtained by dividing the weight by the weight per cubic foot; and in the case of solid beams the width is given by dividing the cubical content by (span × depth).

It will be seen that a diagram drawn even to a small scale, on the system hitherto considered, to be of practical utility in estimating the weights of large girders heavily loaded, would be of inconveniently large dimensions, and to obviate this objection the Author has designed a "unit-diagram," the radius, which represents unity, being divided into one hundred equal parts, each of which therefore represents 0·01. These divisions are ruled the whole length of the diagram, similarly to the five divisions in Fig. 4.

From what has been already said, and by reference to Figs. 2 and 4, it will be clear that as the total weight of a structure divided by the external load represents the proportion of that weight necessary to support a unit of load, and its own weight in addition, this diagram can be used in approximately estimating the weights of structures of any span and load. This is effected by dividing the weight of the sample structure by its load, finding the position of a radiating line equal in length to the quotient (measured by the diagram scale) between the quadrant and the top of the diagram, as at D A (Fig. 4), noting the horizontal line intersecting the circumference at the same point, to which line the scale of spans is to be applied with the reading representing the span in contact therewith, and with the scale in such a position that zero may fall on the line at the top of the diagram; then observing upon which line the reading representing the span of the proposed structure falls, and, from the point in which this line intersects the circumference, measuring another radiating line as at $d' a'$, the length of which, by the diagram scale, after being multiplied by the proposed load, will give the weight of the proposed struc-

ture. The remark already made as to the procedure to be adopted when no data are at hand applies to the unit diagram, but the weight represented by $g\,d$ (Fig. 4) must be divided by the external load before being made use of.

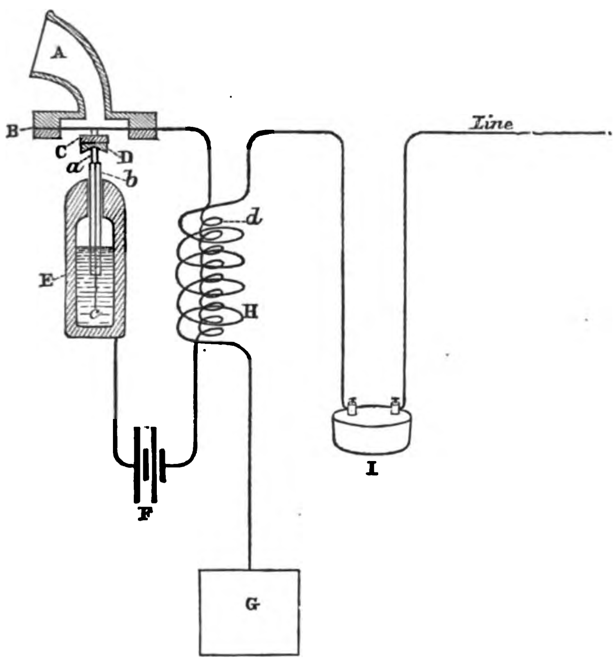
The Paper is accompanied by the diagrams from which the woodcuts in the text have been prepared; also by two unit-diagrams with suitable scales, each with millimetre divisions, but one having a complete quadrant yielding the limiting spans, and with radius = 1 decimetre, each millimetre division therefore representing 0·01, so that the measurements are obtained to two places of decimals; and the other having only a portion of the quadrant, but drawn to ten times the scale, each millimetre therefore representing 0·001, thus enabling the measurements to be read to three places of decimals, but confining its applications to structures of shorter span.

(*Paper No. 1944.*)

"Long-Distance Telephony."

By GEORGE M. HOPKINS, of Brooklyn, N.Y.

TELEPHONIC communication between the cities of New York and Chicago, a distance of 1,000 miles, has recently been established by means of a telephone invented by the Author. The line, belonging to the Postal Telegraph Company, consists of a steel-cored copper wire, having a diameter of $\frac{1}{4}$ inch, the steel portion being $\frac{125}{1000}$ of an inch in diameter. The wire is supported on



poles, spaced from $\frac{1}{40}$ to $\frac{1}{45}$ of a mile apart. The resistance of the wire is $1\frac{2}{10}$ ohms per mile, and the line is in every way of first-class construction. There are two cables in the line, one being about $\frac{3}{8}$ of a mile in length. The perfect character of this equipment contributes greatly to the success of the communication;

but at the preliminary trials the Author's telephone proved superior to all its competitors, and is at present regarded as the only practical instrument for long distance telephony. The apparatus in common use on short lines were found to be quite incapable of talking through the 1,000-mile line.

The following is a description of the Hopkins transmitter:—

A (Fig., p. 197), mouthpiece; B, diaphragm; C, carbon disk attached to the centre of the diaphragm; D, carbon disk poised on a wire *a*, extending through the wooden float-rod *b* into mercury *c* (the disks C D are of extremely hard incompressible carbon); E, iron bottle holding the mercury *c*, and guiding the float-rod *b*. The local circuit includes the diaphragm B, carbon disks C, D, wire *a*, mercury *c*, iron bottle E, two Leclanché cells F, and primary wire *d* of the induction coil. The line circuit is from the ground G through the secondary wire H of the induction coil and receiver, I, to the line. The induction-coil is of the usual construction; the resistance of the secondary is about 200 ohms.

The electrodes C, D, are held in contact when the instrument is at rest, but when the diaphragm is vibrated, the passage of the current is interrupted between the electrodes C, D, owing to the inability of the float-supported electrode to follow the movements of the electrode carried by the diaphragm. It is in this peculiar action of the electrodes that the Hopkins transmitter differs from all others.

(*Paper No. 1901.*)

"Slipway for Pleasure Boats on the River Thames."

By Charles James More, M. Inst. C.E.

In consequence of the great increase during recent years in the number of pleasure-boats on the River Thames, it has been found necessary at several places to provide means of passing small boats from one reach to another without the necessity of their going through the lock. The general construction of these boat-launches, or slipways, is shown in Plate 8, which represents the launch at Sunbury lock. They consist of two inclines with gradients of 1 in 9 or 10, meeting at a point about 1 foot above the head-water level of the higher reach. At the end of each incline, for the convenience of entering and leaving the boat, there is a raised platform, the surface of which is horizontal and slightly above the ordinary level of the water in the river. On the inclines are placed two rows of iron rollers, one for the up and the other for the down traffic. The rollers are 3 feet in width, 3 inches in diameter, and are about 5 feet apart. In order to afford support to the keels of the boats whilst passing from the up to the down incline, a wrought-iron tipping frame, or cradle, is fixed at the summit; the cradle is 10 feet long by 3 feet wide. Steps on each side of the slipway afford communication with the towing-path.

The use of these boat launches is found to effect a considerable saving in time, and, what is of importance where water-power is utilized, in dry seasons greatly economises the consumption of water required for lockage.

This communication is accompanied by a drawing, from which Plate 8 has been prepared.

(*Paper No. 1909.*)

"Two Applications of Calculation to the Resistance of Materials."[1]

By Charles Antoine, of Brest.

(Translated and Abstracted by Prof. W. C. Unwin, B.Sc., M. Inst. C.E.)

The Author published, in "Naval Science" for July 1872, a formula expressing the usage adopted by Lloyd's, the English Dockyards, &c., for the determination of the diameter of rivets in iron ships. The Author wishes to show that this formula, the use of which has extended more and more, leads to a very simple system of proportioning joints of uniform resistance, with a convenient distance between the rivets.

In the second part of the Paper, the Author gives some practical rules for determining the stress in materials, when that stress is due to flexure produced by the forces put in play. He calculates the chances of fracture at the dangerous section, without needing to know the loading forces or to make any calculations of moments of inertia, which are often laborious.

Riveting of Iron Ships.

The rules followed in proportioning the riveting of iron ships appear at first sight very complicated. They may, however, be reduced to very simple formulas expressing the usage adopted in great workshops of construction.

In "Naval Science" for July 1872, at p. 298, the Author gave the following empirical formula for the diameter d of a rivet, in plates of thickness e:—

$$d = 5 \cdot 5 \sqrt{e} \text{ (metric units)}$$

$$= 1 \cdot 1 \sqrt{e} \text{ (English units).}$$

This approximates to a mean between the dimensions calculated from the rules of Lloyd's, Liverpool, the English Dockyards, and

[1] The original Paper is in the Library of the Institution.

the "Bureau Veritas." The following Table shows the comparison in English units[1]:—

Thickness of Plates e in sixteenths of an inch.	Diameter of Rivets in sixteenths of an inch.				
	Formula $d = 1 \cdot 1 \sqrt{e}$.	Lloyd's.	Liverpool.	English Dockyards.	"Bureau Veritas."
5	10	10	10	8	..
6	11	10	10	10	10
7	12	10	12	12	10
8	12	12	13	12	..
9	13	12	13	14	12
10	14	12	14	14	..
11	15	14	14	14	13
12	15	14	15	16	14
13	16	14	16	16	..
14	16	16	18	18	16
15	17	16	19	18	..
16	18	16	20	18	17

It may be added that at L'Orient, where iron construction has assumed a very great importance, they follow a rule for the diameter of the rivets approaching closely to $d = 5 \cdot 5 \sqrt{e}$, with the exception that the diameters chosen are restricted to even numbers of millimetres.

Diameters of Rivets adopted at L'Orient.

Thickness of Plates e.	$5 \cdot 5 \sqrt{e}$.	Diameter in Even Numbers of Millimetres.		Thickness of Plates.	$5 \cdot 5 \sqrt{e}$.	Diameter in Even Numbers of Millimetres.		Thickness of Plates.	$5 \cdot 5 \sqrt{e}$.	Diameter in Even Numbers of Millimetres.	
		By Calculation.	In Practice.			By Calculation.	In Practice.			By Calculation.	In Practice.
1	5·5	6	4	11	18·2	18	18	21	25·2	26	26
2	7·8	8	6	12	19·0	20	18	22	25·7	20	26
3	9·4	10	8	13	19·8	20	20	23	26·4	26	26
4	11·0	12	10	14	20·6	20	20	24	26·7	26	26
5	12·3	12	12	15	21·3	22	22	25	27·5	28	28
6	13·5	14	12	16	22·0	22	22	26	28·1	28	28
7	14·5	14	14	17	22·7	22	22	27	28·6	28	30
8	15·5	16	14	18	23·3	24	24	28	29·1	30	30
9	16·5	16	16	19	24·0	24	24	29	29·7	30	30
10	17·4	18	16	20	24·6	24	24	30	30·7	30	32

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[1] The Table in "Naval Science," which gives the thicknesses of the plates in sixteenths of an inch, is substituted for the Table in Mr. Antoine's paper, which gives the thicknesses of the plates in millimetres.—W. C. U.

By admitting for the diameters of the rivets those which result from the rule $d = 5\cdot 5 \sqrt{e}$ (or in inches, $d = 1\cdot 1 \sqrt{e}$), we obtain very simple rules for the pitch of the riveting.

Consider first a joint with simple lap, and formed of A rows of n rivets each. Admitting $15\frac{1}{4}$ tons per square inch for the resistance of the plates, the total resistance across one of the rows of rivets is

$$R = 15\cdot 25\,(l - n\,d)\,e,$$

l and e being the length and thickness of the plate in inches.

For the resistance to tension of the rivet, 22·88 tons per square inch may be assumed. Since it results from experiments made in England by Mr. Fairbairn, and in France by Mr. Gouin, that the shearing resistance is $\frac{4}{5}$ of the tenacity, the total resistance of $A \times n$ rivets is

$$R' = \frac{4}{5} \times 22\cdot 88 \times A \times n \times \frac{\pi}{4}\,d^2.$$

Equating the resistances to tearing and shearing,

$$0\cdot 94\,A\,n\,d^2 = (l - n\,d)\,e.$$

If the diameter of the rivet is given by the formula $d = 1\cdot 1 \sqrt{d}$, this equation simplifies to

$$1\cdot 12\,A\,n = l - n\,d.$$

The spacing of the rivets from centre to centre is given by the expression

$$E = \frac{l}{n}, \text{ and consequently,}$$

$$E = \frac{l}{n} = 1\cdot 12\,A + d.$$

If the joint is one with double covers, the resistance of each rivet is exercised on two sections, and then for the pitch

$$E = 2\cdot 24\,A + d.$$

Taking in round numbers $1\frac{1}{8}$ and $2\frac{1}{4}$ for 1·12 and 2·24, the following practical rule is obtained. The spacing of the rivet-holes from edge to edge ought to be [1]

30	mm. or	$1\frac{1}{8}$	inch	for	one row	of rivets.
60	,,	$2\frac{1}{4}$	,,	,,	two rows	,,
90	,,	$3\frac{3}{8}$	,,	,,	three ,,	,,
120	,,	$4\frac{1}{2}$	,,	,,	four ,,	,,

[1] In rounding off the English figures it is not possible to give the exact equivalent of the Author's figures. To agree with him exactly, 1·182 should be taken instead of $1\frac{1}{8}$.—W. C. U.

These numbers should be doubled when there is a cover-plate on each side of the joint.

The Author proceeds to compare the results obtained by these practical rules with the usage adopted at the ports of Brest and L'Orient. The anomalies which may be remarked in the spacing of the rivet-holes from edge to edge are due partly to the fact that the distance is usually given from centre to centre. Thus, for iron plates of 15 millimetres, 20 millimetres, and 25 millimetres thickness, and with a single row of rivets, the following dimensions are adopted:—

Thickness of Plates e.	Mean Diameter of Rivets. d.	Mean Pitch E.	Spacing from Edge to Edge of Holes $E - d$.
15	22	57·0	35
20	24	55·8	32
25	28	62·8	35

Spacing of Rivets from Edge to Edge of Holes, reduced to English Measures.

Thickness of Plate.	One Row of Rivets.		Two Rows of Rivets.		Three Rows of Rivets.		Four Rows of Rivets.	
	Brest.	L'Orient.	Brest.	L'Orient.	Brest.	L'Orient.	Brest.	L'Orient.
ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
0·20	1·02	1·18	2·01	2·32	2·91	3·46	..	4·61
0·24	1·14	1·02	2·24	1·97	2·99	2·91	..	3·86
0·28	1·30	1·18	2·56	2·24	3·86	3·39	..	4·49
0·32	1·46	1·02	3·11	2·40	4·33	2·95	..	3·94
0·35	1·61	1·18	3·15	2·32	4·80	3·43	..	4·53
0·39	1·46	1·10	2·87	2·32	4·33	3·11	..	4·09
0·43	1·61	1·26	3·19	2·40	4·72	3·58	..	4·72
0·47	1·50	1·14	2·95	2·20	4·33	3·27	..	4·33
0·51	1·65	1·30	3·23	2·52	4·88	3·74	..	4·92
0·55	1·54	1·22	3·03	2·36	4·53	3·70	..	4·84
0·59	1·65	1·38	3·27	2·44	5·39	3·94	..	5·20
0·63	1·57	1·30	3·11	2·48	5·47	3·86	..	4·88
0·67	1·50	1·22	2·95	2·36	4·41	3·46	..	4·61
0·71	1·42	1·38	2·79	2·64	4·17	3·90	..	5·16
0·75	1·34	1·30	2·64	2·52	3·94	3·70	..	4·88
0·79	1·26	1·26	2·48	2·40	3·78	3·50	..	5·24
0·83	1·22	1·38	2·36	2·48	3·58	3·94	..	5·20
0·87	1·18	1·34	2·28	2·56	3·43	3·74	..	5·35
0·91	1·26	1·42	2·17	2·44	3·27	3·58	..	4·76
0·94	1·06	1·42	2·09	2·72	3·15	3·98	..	5·28
0·98	1·02	1·38	2·01	2·60	3·03	3·86	..	5·47
1·02	..	1·34	1·93	2·52	2·91	3·70	..	4·88
1·06	..	1·46	1·85	2·76	2·80	4·09	..	5·39
1·10	..	1·42	1·81	2·76	2·72	3·98	..	5·20
1·14	..	1·34	1·73	2·64	2·60	3·82	..	5·04
1·18	..	1·50	1·69	2·83	2·52	4·25	..	5·83

Determination of the Amount of Fatigue of Bent Pieces.[1]

Two groups of formulas serve to resume the principal laws of resistance to flexure of parts of structures.

The one, $\frac{R\,I}{\epsilon} = m$ states the effects which the couples of flexure exercise on the resistance of the piece.

The other, $E\,I\,\frac{d_2\,y}{d\,x^2} = m$, indicates the form of the bent solid.

In these formulas m represents the bending couple; R the safe stress on unit area of the material. Also, I is the moment of inertia, which is for a rectangle $I = \frac{a\,b^3}{12}$; for a circle $I = \frac{\pi\,r^4}{4}$; for an annular section $I = \frac{\pi}{4}(r^4 - r_1{}^4)$; ϵ is the distance of the fibre which is the most distant from that which is termed the neutral fibre. E the coefficient of elasticity of the material.

If, for example, a rectangular piece of length l be considered fixed at one of its extremities, and loaded at the other by a weight p, it is known that any point at a distance x from the fixed end is subjected to the action of a bending couple—

$$m = p\,(l - x) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

That couple is greatest for $x = 0$, and it is at the fixed end that the section most strained, and commonly termed the dangerous section, occurs.

Two successive integrations of the equation—

$$E\,I\,\frac{d_2\,y}{d\,x^2} = p\,(l - x)$$

give, remembering that for $x = o$, $\frac{d\,y}{d\,x} = o$, and $y = o$,

$$E\,I\,y = \frac{p\,x^2}{6}\,(3\,l - x).$$

These are well-known facts, which the Author asks permission to state, in order to explain the object of this note, viz., to substitute for formulas too complicated to be convenient, other formulas deduced from them, and of a more practical character. This assumed, let an example be taken:—

A beam of oak, solidly fixed at both extremities, supports half

[1] Mr. Antoine uses the word fatigue in an unusual sense, in place of amount of stress.

the weight of a number of men lying in their hammocks. The dimensions of this beam are:—

Length, 336 inches; height, 11·2 inches; width, 8·8 inches.

The load deflects the beam $\frac{1}{2}$ inch.

Is there any danger of fracture?

What is the stress at the dangerous section?

How many men with their hammocks could be added without exceeding the limits of safety?

What would be the deflection with this new load?

The formulas given by the theories of elasticity for the case of a beam *encastré* at both ends, and loaded with a weight w per unit of length, uniformly distributed, are as follows:—

$$m = \frac{w\,l^2}{12} = \frac{R\,I}{\epsilon} \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$E\,I\,f = \frac{w\,l^4}{384} \quad \ldots\ldots\ldots\ldots \quad (2)$$

From the data of the problem, putting $E = 1{,}700{,}400$, $R = 853$, calculation, sufficiently tedious it is true, shows that the load per unit of length which produces the given deflection is $w = 2 \cdot 32$ lbs. per inch, and that the stress at the dangerous section is $R^1 = 1{,}265$ lbs. per square inch.

The value of R admitted for wood is 853, and it is so much the less reasonable to permit a greater stress, that the rolling and pitching will produce shocks. To reduce the load to a point of safety, it is necessary then to remove a third of the hammocks, if there is not time to strengthen the beam supporting them.

From the preceding example it may be inferred that, in fact, calculations of this kind are little used in practice when a prompt decision is required to avoid dangers always imminent in navigation.

However, it is by the flexure more or less great that the importance of the forces in play can be learnt and the value of the strengthening which ought to be undertaken. It is unnecessary to disregard the indications thus given immediately. For these long and laborious calculations, which risk additional chances of error, there may be substituted a formula such as $f\,b = K\,l^2$, in which f and b express the deflection and height in inches and l the length in inches; K a coefficient which depends on the nature of the material and its mode of support.

Put R_0 for the stress admitted at the dangerous section; f_0 the deflection which corresponds to this stress, and let again, for

example, a beam be taken, fixed at both ends and loaded uniformly. The formulas are—

$$\frac{R_0 I}{\epsilon} = \frac{w l^2}{12} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$E I f_0 = \frac{w l^4}{384} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Divide equation 2 by equation 1; then, remembering that, for a piece symmetrical about the neutral axis, $\epsilon = \frac{b}{2}$,

$$b f_0 = \frac{2 R_0}{E} \times \frac{12}{384} l^2.$$

If for oak, $E = 1,706,400$, and the limiting stress allowed is $R_0 = 853$,

$$b f_0 = 0 \cdot 0000312 \, l^2.$$

Thus whatever be the width, the moment of inertia, the form even of a piece, provided it is of uniform section, and symmetrical about the neutral axis, we have always, if it is of wood with a resistance of 853 lbs. per square inch, and a coefficient of elasticity of 1,706,400 lbs. per square inch,

$$f_0 = \frac{0 \cdot 0000312 \, l^2}{b},$$

when it is loaded uniformly and fixed at both ends. The formulas (1) and (2) show that the deflection f and the efforts R are respectively proportional to the weight w per unit of length, and in consequence proportional to each other.

The comparison of the observed deflections in any given case with the deflection corresponding to a known value of the resistance R_1 gives the actual value of the stress at the dangerous section.

Going back to the example previously stated, for the normal case $R_0 = 853$; $E = 1,706,400$ length $l = 336$ inches; and height $11 \cdot 2$ inches,

$$f_0 = 0 \cdot 0000312 \frac{336^2}{11 \cdot 2} = 0 \cdot 314.$$

But the beam has a deflection of $\frac{1}{2}$ inch. Then the stress at the dangerous section is

$$R_1 = 853 \times \frac{0 \cdot 5}{0 \cdot 314} = 1,356 \text{ lbs. per square inch.}$$

A cylinder of wood of the same length would have the same stress when deflected $\frac{1}{2}$ inch.

A beam in wood of 945 inches length, 12 inches height, fixed at both ends and loaded uniformly ought not to have a deflection greater than

$$f = \frac{0 \cdot 0000312 \times 945^2}{12} = 2 \cdot 32 \text{ inches.}$$

Designate by E^1 the coefficient of elasticity of any other material, R_1 the stress per square inch which may be allowed; E_0, R_0, the corresponding values for oak; it is easy to see that the normal deflection f_1 for the new material, forming, for example, a beam fixed at both ends and uniformly loaded, is given by the equation

$$f_1 = 0 \cdot 0000312 \frac{2 R_1}{E_1} \times \frac{E_0}{2 R_0}.$$

For Wood . . . $R_0 = 853$; $E_0 = 1{,}706{,}400$; $\frac{E_0}{2 R_0} = 1000$;

Wrought iron $R_1 = 8532$; $E_1 = 28{,}440{,}000$; $\frac{2 R_1}{E_1} = 0 \cdot 0006$;

Steel . . . $R_1 = 22752$; $E_1 = 29{,}900{,}000$; $\frac{2 R_1}{E_1} = 0 \cdot 00152$;

Cast steel . $R_1 = 31284$; $E_1 = 42{,}660{,}000$; $\frac{2 R_1}{E_1} = 0 \cdot 0133$;

Grey cast iron $R_1 = 4266$; $E_1 = 12{,}800{,}000$; $\frac{2 R_1}{E_1} = 0 \cdot 00066$.

Thus the formula which gives the normal deflection, corresponding to the values of R_1, for a solid fixed at both ends and uniformly loaded, will be for

Wrought iron . . . . . $f b = 0 \cdot 00001872\ l^2$;
Ordinary steel . . . . . $f b = 0 \cdot 000047\ l^2$;
Cast steel . . . . . . $f b = 0 \cdot 000041\ l^2$;
Grey cast iron . . . . . $f b = 0 \cdot 000020\ l^2$.

Example.—What is the value of the coefficient R_2, when a round bar of wrought iron of 320 inches length, 2 inches in diameter, takes a deflection of 0·6 inch? From the formula

$$f b = 0 \cdot 00001872\ l^2,$$

the normal deflection corresponding to $R = 8{,}532$ lbs. is

$$f = 1 \text{ inch nearly.}$$

The stress due to a deflection of 0·6 inch will therefore be

$$R_2 = 8{,}532 \frac{0 \cdot 6}{1} = 5{,}119 \text{ lbs. per square inch.}$$

Thus far the case considered has been that of a solid *encastré* at both ends and uniformly loaded. In the same way may be found the following values of the coefficient K in the general formula

$$f\,b = k\,l^2$$

in the following cases:—

I. Solid resting on two supports and loaded uniformly by a weight w per unit of length.

$$\left(m = \frac{w\,l^2}{8};\ \ \mathrm{E\,I}\,f = \frac{5}{384}\,w\,l^4\right).$$

Wood $k = 0 \cdot 000104$; wrought iron, $0 \cdot 000063$; ordinary steel, $0 \cdot 000158$; cast steel, $0 \cdot 000139$; grey cast iron, $0 \cdot 000069$.

II. Solid on two supports loaded at the centre by a weight P

$$\left(m = \frac{\mathrm{P}\,l}{4};\ \ \mathrm{E\,I}\,f = \frac{1}{48}\,\mathrm{P}\,l^3\right).$$

Wood $k = 0 \cdot 000083$; wrought iron, $0 \cdot 00005$; ordinary steel, $0 \cdot 000127$; cast steel, $0 \cdot 000111$; grey cast iron, $= 0 \cdot 000055$.

III. Solid, fixed at both ends, and loaded uniformly by w per unit of surface

$$\left(m = \frac{w\,l^2}{12};\ \ \mathrm{E\,I}\,f = \frac{w\,l^4}{384}\right).$$

Wood $k = 0 \cdot 000031$; wrought iron, $0 \cdot 000019$; ordinary steel, $0 \cdot 000047$; cast steel, $0 \cdot 000042$; grey cast iron, $0 \cdot 000021$.

IV. Solid, fixed at both ends and loaded by a weight P at the centre.

$$\left(m = \frac{\mathrm{P}\,l}{8};\ \ \mathrm{E\,I}\,f = \frac{1}{192}\,\mathrm{P}\,l^3\right).$$

Wood $k = 0 \cdot 000042$; wrought iron, $0 \cdot 000025$; ordinary steel, $0 \cdot 000066$; cast steel, $0 \cdot 000055$; grey cast iron, $0 \cdot 000028$.

V. Solid, fixed at one end, and loaded uniformly by a weight w per unit of length

$$\left(m = \frac{w\,l^2}{2};\ \ \mathrm{E\,I}\,f = \frac{1}{8}\,w\,l^4\right).$$

Wood $k = 0 \cdot 00025$; wrought iron, $0 \cdot 00015$; ordinary steel, $0 \cdot 00038$; cast steel, $0 \cdot 000333$; grey cast iron, $0 \cdot 000165$.

VI. Solid, fixed at one end, and loaded by a weight P at the other end

$$\left(m = P\,l;\ E\,I\,f = \frac{1}{3}\,P\,l^3\right).$$

Wood K = 0·000333; wrought iron, 0·0002; ordinary steel, 0·000506; cast steel, 0·000443; grey cast iron, 0·000220.

The application of these formulas requires that there should be known exactly the mode of application of the forces acting on the body, whether at the centre or uniformly distributed. But generally these forces are not single, and the body, the fatigue of which is to be ascertained by means of its deflection, is subjected to forces distributed in an undetermined way. If, then, the stress cannot be exactly known, at least the limits within which it is comprised may be ascertained.

Only prismatic solids have been considered. The deflections of other solids varies according to their special form. A solid of equal resistance, for instance, takes for a given load double the deflection of prismatic solids of the same section at the dangerous section. The Author's aim in preparing this note has been to furnish a means, especially for officers of the Navy, to find rapidly the degree of safety of pieces bent in ordinary course of sailing. A spar of 100 feet length and of 22 inches diameter, supposed fixed at its centre, might take a deflection of 4 inches without danger, if it were cylindrical, and 8 inehes if it had exactly the form of a solid of equal resistance. The Author would, however, for prudence only allow 4 inches of deflection.

(*Paper No. 1913.*)

"Wire-Rope Street Railroads in San Francisco and Chicago, U.S.A."

By WILLIAM MORRIS, M. Inst. C.E.

THE Author, when recently passing through San Francisco and Chicago, had an opportunity of examining into the construction and working of the wire- or cable-rope system of street railroads, or tramways, in operation in the above cities. Believing that comparatively little is known of the system in this country, the Author is induced to give a general description of it.

By this system, a car, with its coupled "dummy" in front, and when both are fully loaded with passengers, forty-four in all, can be drawn up and down gradients of 1 in 5 with ease and security. These wire-rope street railroads are of great importance to a city like San Francisco, surrounded more or less by high ground, rising in many places directly from the busiest part of the city. Previous to the introduction of street railroads, the property on these steep roads was of little value; but their advent has been the means of doubling, and, in some cases, trebling, it in value.

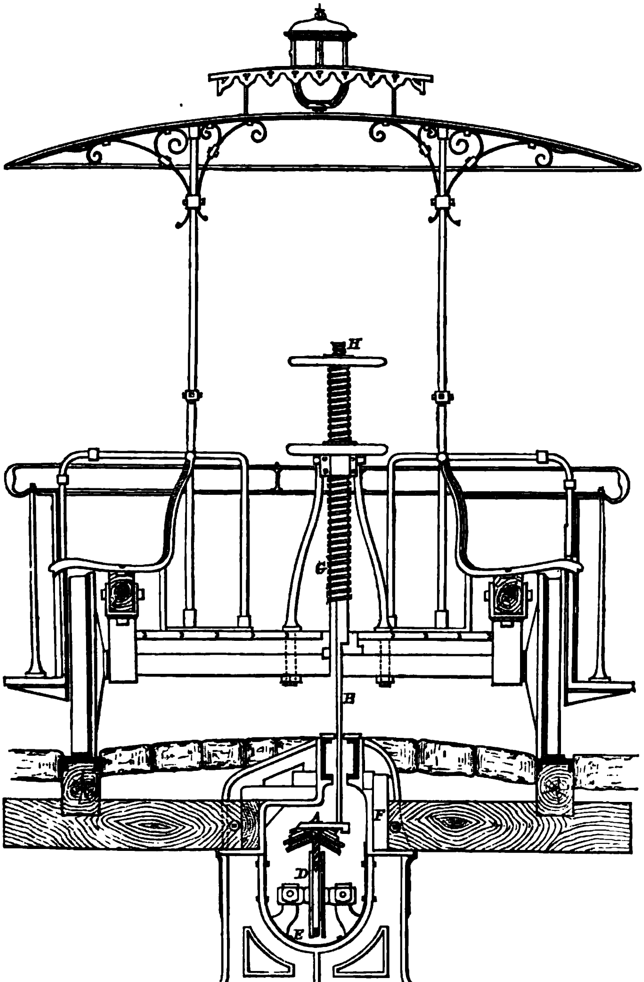
It should be mentioned, that the temperature in winter at San Francisco does not often fall below 50° Fahrenheit, therefore the question of how far ice and snow would interfere with its successful working cannot be tested there; and the Company owning the road at Chicago has not experienced any trouble from this source. The patentee of this system proposes a cheap method of warming the tube, to remove ice and snow; another suggestion is the free use of bay salt, to be removed by scrapers.

There are several wire-rope street railroads in operation in San Francisco. The Author was shown over more particularly the "Clay-street" railroad, which it is proposed to describe. This road has a double track of about 5,500 feet in length, of 3 feet 6 inches gauge; the summit of the hill is 307 feet above its starting-point, rising this height in a distance of about 2,475 feet, giving an average gradient of a little over 1 in 8, the steepest being 1 in 6.

The general appearance of the road is the same as that of a horse-track line, except that in the centre of each track there is

an opening, or slot, the entire length of the road, of about $\frac{3}{4}$ inch in width. Below the surface, and about the centre of each track, there is a channel, or tube, of such dimensions as to give room for

FIG. 1.



Scale $\frac{1}{10}$th real size.

the steel wire-rope, and the sheaves which support it, to work freely therein. The tube also protects the "gripper," A, Fig. 1, attached to the dummy on the track by means of a flat bar of iron,

which passes up through the slot, and forms the connection between it and the rope. The throwing of the "gripper" into action, by grasping the rope, produces the necessary motion of the car, which of course travels with the same velocity as the rope. The $\frac{3}{4}$-inch opening, or slot, is to permit the shank, B, Fig. 1, which passes up from the gripper, A, in the tube to the dummy, to travel through it when the car is in motion. This slot is not placed immediately over the centre of the tube, but on one side, so that grit, or other matter, falling through does not lodge on the wire-rope, but falls to the bottom of the tube; it also enables the gripper to pass by and under the upper sheaves, C, Fig. 2, and over the lower sheaves, D, Fig. 1, in the tube.

The endless wire-rope travels down one track and up the other. At the summit the rope is turned on to one series of pulleys, 8 feet in diameter, and led into the engine-house, and then out again in a similar manner by another series of driving pulleys of the same diameter, the rope being made to take a right-angle turn to the left and right after leaving the engine-house. At each terminus of the road the wire-rope passes half round a horizontal sheave, or pulley, 8 feet in diameter, fixed to a carriage which is capable of moving horizontally, for the purpose of keeping a uniform tension on the rope as it becomes slack or tight.

The sheaves, D, Fig. 1, supporting the rope in the tube, are about 11 inches to 12 inches in diameter, placed about 30 feet apart, and secured to cast-iron standards, with man-hole doors in the surface of the street to give access to them. The sheaves on the Chicago road are formed in two halves bolted together, with wood in between, upon which the rope runs: the wood portion of these sheaves has to be taken out and renewed every two months. Intermediate cast-iron standards are placed 3 to 4 feet apart to support the rails in the centre of the track, which are within $\frac{3}{4}$ inch of each other, thus forming the continuous opening, or slot.

Lengths of sheet-iron tubing bent to the required form, E, Fig. 1, and extending to within 15 inches of the surface of the street, are secured by bolts to the cast-iron standards; earth is then rammed under and against the sides of the tubing. To prevent the earth from getting into the tube above the ironwork, a 3-inch plank, F, Fig. 1, is placed on end on the standards; the upper edge coming up to the level of the underside of the continuous central rail. A bracket on each side of the cast-iron standards supports one end of a transverse sleeper, to which it is bolted; the other end of the sleeper rests in the solid ground of

the road ; to these sleepers are notched longitudinal timber bearers, which carry the street rail on which the car runs.

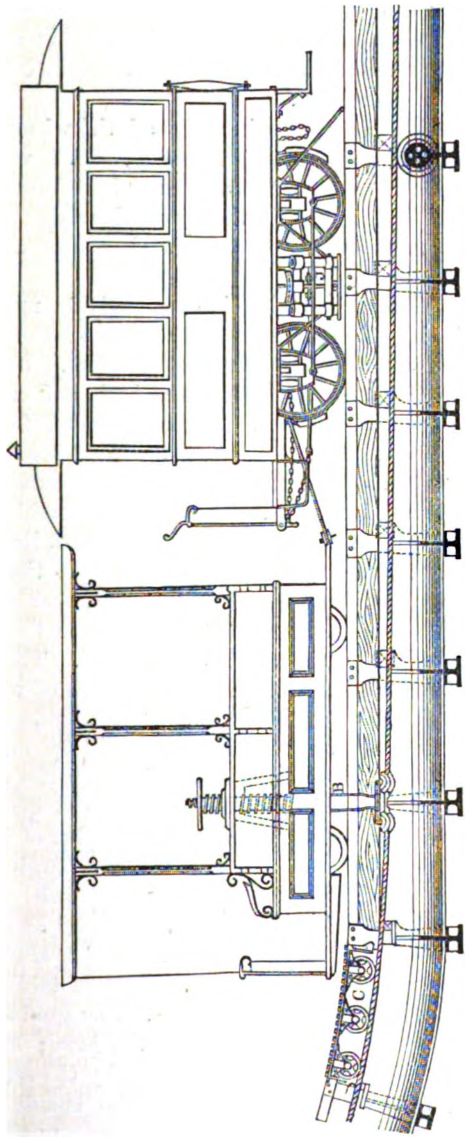


Fig. 2.

Scale 1 inch = 4 feet.

Another method of constructing these street railroads, of which several miles have been laid in San Francisco, is as follows :—

Instead of cast-iron standards, an ordinary railway bar is bent to the required form; this is braced and arranged to carry the two rails forming the continuous slot, as also the rails on which the car travels. The sheet-iron tubing, as in the Clay-street railroad, is dispensed with, and a Portland cement concrete culvert, or tube, is constructed in place of it.

Where there is a steep rise in the road the wire-rope has to be kept down by the small upper sheaves, C, Fig. 2, which are from 6 inches to 8 inches in diameter, and fixed in a frame between two of the cast-iron standards. If the rope is leaving the summit and descending, it is made to pass over a sheave of about 4 feet in diameter.

The endless wire-rope, which is constantly in motion, is about 11,000 feet in length, 1 inch in diameter, formed of crucible-steel wire, composed of six strands of nineteen wires. Each wire has a tensile strain of 160,000 lbs. per square inch, and can be bent in any direction without fracture. The wire-rope is found to stretch 1 per cent. of its length before being too much weakened for use. For taking up the slack of the rope a cast-iron frame, or bed-plate, is erected in the engine-house. This frame resembles a lathe-bed, standing about 4 feet 6 inches above the ground, its length being about 50 feet. A transverse frame is fitted to the bed-plate, to which are attached pulleys 8 feet in diameter, over which the rope passes; the frame with its pulleys is made to travel along the bed-plate for taking up the slack as required. The average life of the rope is about fifteen months. On some of the street railroads the length of rope is 17,000 feet. The success of this system of street railroad, or tramway, depends chiefly on the kind of "gripper" employed to obtain a firm hold on the wire-rope, and the facility with which it can be engaged and disengaged. On the end of the shank B, Fig. 1, which is a flat bar of iron, 5½ inches wide by ⅝ inch thick, working through the longitudinal slot, is the gripper attachment. This consists of two pairs of small sheaves, about 3½ inches in diameter, and placed at an angle, each pair being about 10 inches apart and secured to sliding frames, in which are also placed jaws, for the purpose of taking a firm hold of the wire-rope. The small sheaves act as guides, in the first instance, for the rope to pass between the jaws; but afterwards these are gradually tightened on the rope by the screw G, Fig. 1. The dummy, through the medium of the shank and sheaves, gradually acquires the momentum of the rope, until the gripping jaws are brought into action and firmly take hold of it by means of the small screw H, Fig. 1. Motion is given to the wire-rope

by two horizontal engines of about 100 HP. each, one engine being kept in reserve. The speed of the rope is 6 miles per hour, running for sixteen hours a day; and during this time the engines consume about 2,900 lbs. of small coal. The total cost of the engines and machinery was about £3,000. Those in charge of the rope can easily, it is said, tell when a strand becomes broken, by a certain unevenness in the running; there is, besides, a tell-tale, fixed in the engine-house, which also gives warning. Further, a length of 50 feet of rope is always exposed, and in view in the engine-house.

With regard to the best gauge for these roads, the Author was informed by the engineer of the company, who had constructed other lines in the city of 5-feet gauge, that in his opinion a gauge of 3 feet 6 inches was equally effective as the broader one, and often more convenient to adopt, as taking up less of the surface of the streets.

A double-track road, with a tube 30 inches deep, costs, on an average, £10,000 a mile, excluding rolling stock. For a tube 12 inches in depth, the cost would probably be about £8,000.

The dummy carries eighteen passengers, and the car twenty-six. Both vehicles are provided with powerful brakes, which on such steep gradients become a matter of the greatest importance for security against accidents. The engineer of the company, riding with the Author over the road, had the brakes applied to the dummy and car while descending a gradient of 1 in 6; the vehicles were brought to a standstill in a very short distance, without any violent shock, in fact they were under perfect control. As some verification of this, it was stated that there are four or five of these lines in operation in San Francisco, running cars every five minutes for sixteen hours a day, yet there had never been a case of a runaway car.

The car, besides the usual brakes to the wheels, has, between each pair of wheels, a brake, J, Fig. 2, which presses vertically on the rails. It is 28 inches long, and is powerful enough to lift the car off the track when empty. The wheels of the dummy have the usual brakes, but the dummy is further provided with a powerful brake, worked by the foot. This brake spreads apart levers, having at their feet shoes which press at an angle of 45° inwards on the rail.

In working the system, and for the purpose of changing the car and dummy from one line to the other, a crossover line and a turntable are provided at the termini of the road. When approaching the terminus, the conductor on the dummy disengages

the gripper from the rope, and also uncouples the car; the dummy travels by its own momentum over the cross road to the opposite track, to connect with the car which has continued on the original line to the turntable, and is afterwards brought to the rear of the dummy and connected, when it is again ready to start on its journey.

It should be mentioned that all the wire-rope street railroads are straight from end to end, with the exception of one, on which there is an angle of 45°. To overcome the turn at this angle, the rope is deflected by two horizontal sheaves, 8 feet in diameter, and further means are provided by the introduction of other horizontal pulleys, to prevent an undue side strain being brought on the shank while passing round the curve, the tendency of the rope being to come inwards.

Where two wire-rope roads cross at right angles, an arrangement is made for the gripper of one road to be disengaged while passing over the other, the momentum being sufficient to carry the vehicles over the short distance without the aid of the rope.

The Author finds from the published returns that in the case of three important tramways in London worked by horses, the average cost of working and maintenance amounts to 79 per cent. of the gross receipts, permitting an average rate of dividend of about 8·5 per cent. on the ordinary share capital of the companies. It is claimed that the cable-system can be worked at from 37 to 40 per cent. of the gross receipts. The Author is of opinion, after a careful estimate, that it is not at all unlikely that the cost for this system would, on an average, come out to about 45 per cent. of the gross receipts. If this percentage were realised, the average rate of dividend would then amount to 26 per cent. on the ordinary share capital of the London companies referred to, as against 8·5 per cent. now earned. Again, assuming the cost of working and maintenance to reach 50 per cent. of the gross receipts, then the average rate of dividend would amount to 23·3 per cent. on the ordinary share capital, as against the previous 8·5 per cent. The cost of maintenance and working of the Dewsbury, Batley, and Birstal tramway, by Messrs. Merryweather's steam tramway engines, amounts to 58 per cent. of the gross receipts; this tramway has gradients on it of 1 in 20. The North Staffordshire tramway is worked by steam, at 65 per cent. of the gross receipts. Similarly for the three London tramway companies, the cost per car-mile, excluding maintenance of permanent way in each case, amounts to 9·5*d.*; if worked by the cable-road system, the average cost per car-mile would be about 4·46*d.* The cost per car-mile on

the Dewsbury, Batley, and Birstal tramway amounts to 5·82*d.*, and on the North Staffordshire tramway to 9*d.* Comparing the foregoing figures, it will be seen that the cost of working the London tramways on the cable-system would be reduced 50 per cent. The Dewsbury, Batley, and Birstal tramway could be worked at about 25 per cent. less on the cable-system, and the North Staffordshire tramway at 50 per cent. less.

A further advantage of the cable-system is, that it can take full cars of passengers up gradients of 1 in 6, which no horse or locomotive-engine could accomplish, and this at a very slight increase in the cost of working. Four lines of tramway in San Francisco, of a total length of 9½ miles of double line between them, convey 12,750,000 passengers per annum (up gradients of 1 in 6), or at the rate of 1,340,000 passengers per double mile of line; the number of passengers carried annually on the three London tramways, amounts to 79,500,000, or 1,250,000 per double mile of line.

As far as the Author could learn, there are of this system about 25 miles (double lines), in operation in San Francisco and Chicago: the company owning the horse-tramways in the latter city are gradually changing their system, which is 27 miles of single track, to the cable-system, 4½ miles having already been converted. Similarly, in San Francisco, a long length of tramway worked by horses, was seen by the Author being changed to the cable-system.

With reference to the public safety, the Author is of opinion that the cars could be brought to a standstill with equal facility by each system. The cable-system is very suitable for large cities, as there would be no fear of the horses in the streets taking fright when meeting the cars; this is proved by many years' experience. Such a result, however, could hardly be expected in the case of steam-tramway locomotives, which if used in a crowded city might lead to accidents, but in the less crowded provincial towns, the risks would probably be very small. In the running of the cars on the cable-system, there is less noise than when they are drawn by horses; the Author considers that bells should be attached to the cars, or other means taken, to warn foot passengers of their approach.

The Author has been informed, that the cable-road in Chicago has recently been continually used with 2 feet depth of snow on the ground, while those worked by horses were stopped. By means of scrapers and other arrangements, the cable-road is cleared automatically of snow, which is cast up on each side of the track, and so allows the running of the cars to be continued.

The Author thinks it would be desirable to get rid of the dummy, and to have all the working gear on the front of the passenger-car. The engineer of the road under description stated he was preparing designs with this view, to send to England for a proposed tramway.

The rope-system, though originally intended to overcome very steep gradients, is equally applicable for level roads, such as in the city of Chicago, where the streets are nearly all level.

The Author wishes to express his thanks to Mr. George Truswell, Secretary and Manager of the Dewsbury, Batley, and Birstal Tramway Company, for his kindness in placing at his disposal information as to the cost of working the tramway under his management; also to the Engineer, Secretary, and Manager of the Clay-street Railroad Company, for their attention and courtesy in explaining all matters of detail in connection with the construction and working of these street railroads, and to whom also he is indebted for plans and particulars from which the foregoing has been prepared.

The Paper is accompanied by diagrams from which the woodcuts in the text have been prepared.

(*Paper No. 1919.*)

"The Raising and Moving of Buildings Bodily."[1]

By SAMUEL GEORGE ARTINGSTALL, Assoc. M. Inst. C.E.

In the following short description of the means adopted in the United States for raising and moving heavy buildings, it is intended to illustrate the ordinary method by one or two examples, although every building presents difficulties peculiar to itself and to the locality.

The same tools are used, and the same general methods followed, for raising all classes of buildings, whether large or small, or whether constructed of wood or of masonry, the number of screws employed with the necessary cribwork being proportional to the size and weight of the structure. The repeating of many similar parts which are serviceable in all cases, and used many times over, is of great advantage, and reduces the cost of the work by distributing the first expense of the tools over many operations.

All buildings before being moved have to be raised from their foundations. The preparation for this, particularly in large masonry structures, is generally the most costly part of the work, and consumes the most time.

Vigilant supervision and careful precautions must be taken to have the base of the cribwork firmly bedded in the ground, to form a solid and unyielding foundation to support the screws, to ensure as nearly as practicable their simultaneous working, so that the rate of motion may be uniform at all points. Carelessness in these matters results in unsightly cracks in the walls, if no worse consequences follow. The success of the work depends greatly upon the care and vigilance of the men in charge, and neglect at any point is sure to be followed by disaster.

The principal tool used is a jack-screw of cast iron (Plate 9, Fig. 5). It is 21 inches long and 3 inches in diameter, with large spherical head, and it works in a cast-iron nut 4 inches long with projecting flange or collar on the top, and two feathers on the side to

[1] An interesting account of this operation was given in Mr. David Stevenson's "Sketch of the Civil Engineering of North America," published in 1838, and of which a second edition appeared in 1859.—SEC. INST. C.E.

prevent it turning in the screw-block. A loose cap of cast iron is interposed between the head of the screw and the sill timbers, which increases the bearing on the wood and allows the screw to turn freely. Each nut is set and fitted into a screw-block of clear, straight-grained white oak, 4 inches thick, 10 inches wide, and 3 feet long.

The cribwork, which carries the screws to support the structure, is built up of pine timber 6 inches by 6 inches, the pieces at right angles to the wall being 3 feet long; the longitudinal pieces are of various lengths, but always long enough to span two or more cribs, laid so as to break joint in every course, and bonding the whole line together, making in effect one crib 3 feet wide and of the length of the wall to be raised.

The "pump-screw," so called by the workmen on account of the log being bored out similar to a wooden pump, is the agent for moving the building, and also for supporting girders and parts of the structure, where it is impossible or inconvenient to build cribs and supports in the ordinary manner. It is a straight-grained piece of white pine 8 inches square, bored out at one end to receive a jack-screw (Fig. 5). The log is counter-bored and the nut fitted in the end. The above tools, with the addition of a considerable quantity of timbers of various sizes and lengths for needles, sills, slide-blocks, wedges, &c., are sufficient to raise and move buildings of any size or weight.

The building selected for illustration is situated in the City of Buffalo, N.Y., and is owned by the New York, Lackawanna and Western Railroad Company (Plate 9, Figs. 1a, 1b, 2a, 2b). It has a frontage of 90 feet by 80 feet deep, and is four stories in height, built of brickwork with stone facings. The first story is divided into four compartments by three interior brick walls 12 inches in thickness. These walls are continuous the full depth of the building and support the floors above. There are also two large masonry fireproof vaults two stories high in the building. The outside walls are 16 inches thick. The front of the building is supported on stone piers between each store, and by cast-iron columns (Figs. 2a and 2b). The building was originally built and owned by the U.S. Government, and was used for a custom house; it was afterwards altered into stores and business offices, and at present is occupied wholly by the railroad company.

In June 1882, to afford additional room for lines of railroad, the building was raised 5 feet and moved back 35 feet. The work was done so smoothly that there was no interruption of business or interference with the occupants during the operation.

The transfer was commenced and finished in forty days. The work of raising occupied fifty men three days after the screws were placed in position. The building was moved at the rate of 12 feet per day, which is somewhat below the average speed for such a structure. A rate of 20 feet per day is not unusual. The greatest care was taken in laying the sills and sliding-timbers level and firm, and in keeping them well greased with tallow and soap; the weather was wet, and the temperature moderate, which was very favourable for the operation, preventing dust and sand blowing on the grease and keeping it firm. It is evident that by having the sliding-surfaces smooth and level, and the lubricant clean and free from dirt and foreign matter, friction is much reduced; and the operation is performed smoothly with a smaller expenditure of power, and in less time than is the case when the weather is hot, dry, and dusty, the grease soft or nearly fluid, and it is impossible to keep it clean. About thirty-four days were occupied in making preparation for the work, in inserting the needle-beams, building cribs, placing the screws, sills, and sliding-timbers in position ready for moving; and, after the building had been shifted, in removing the screws, taking out the slides and blocks, and leaving the structure ready for the masons to build the permanent foundations under it. The average number of men employed (except during the three days previously mentioned) was fifteen; five hundred screws were used in raising the building, and twelve screws were necessary to move it. The consumption of timber for all purposes was 6,500 cubic feet; of which the greater part had been used for similar works before, and was again serviceable for other purposes.

The first operation is to insert needle-beams under the first floor through all the walls; these needles are pine timber 12 inches square in cross-section, about 8 feet long, projecting equal distances on both sides of the wall. They are spaced as nearly as practicable 4 feet apart from centre to centre, and great care is taken to obtain a level and firm bearing in the holes cut through the walls to receive them; at the same time the ground is excavated on both sides of the wall, and an unyielding and level foundation prepared for the cribwork. The first pieces of timber forming the cribs are 3 feet long, set at right angles to the wall, and spaced so that the centre of each crib is directly under one of the needles. They are firmly bedded in the ground and laid level one with the other. On these are placed the longitudinal pieces extending over two or more cribs, which are built up with alternate courses header and stretcher until the required height is reached. When

completed there is a continuous crib on both sides of the wall, 3 feet wide and equal in length to the wall to be raised. Sills of pine 12 inches by 12 inches are then placed under the ends of the needles, the screws are set in pairs, one pair on each crib, with the loose caps bearing under the longitudinal sills.

For the front of the building, which is supported on stone piers and iron columns, the masonry foundation is cut from under one-half of two adjacent columns; a pine beam 12 inches square in cross-section is then inserted across the opening and under the columns, needle-beams are put beneath this timber, the cribs are built and the sills and screws placed in position, and operated until they just support the columns but do not raise them. This process is repeated until the whole of the front is sustained on the screws (Fig. 2a).

All bearings on the temporary work are now carefully examined, and all inequalities and defects made level with pine wedges. The screws being in position under every part of the structure, and brought up to a firm bearing, the operation of raising is commenced. The workmen are arranged in pairs in such manner as to be opposite each other on both sides of the wall; every man has from twelve to fourteen screws to operate, and to ensure simultaneous motion, the foreman gives a signal, generally by whistle. Each man thereupon advances the screw under his control one-half revolution, and moves to the next, until all the screws under his charge are advanced an equal distance. This process is repeated, when the signal is given, and the building is gradually raised (Fig. 3) without injurious disturbance to the structure; so smoothly is the work performed, that a stranger would not be able to detect anything unusual going on.

By the first few turns of the screws the intermediate parts of the walls between the needles are torn away from the foundations; but these parts are closely watched, and, if any unusual binding is observed, they are cut out with chisels.

After all the screws have been advanced a distance of 12 inches, the work of fleeting (Fig. 6) is commenced, and the necessity of two pairs of screws under each needle is here apparent. The cribs are built up two courses in height, when one of the two pairs of screws is taken out and placed on top of the cribs as raised, and tightened up to a firm bearing. The remaining pair is then removed, placed on the top and tightened. The operation is repeated until all the screws under the building have been raised, and the structure is lifted to the height desired. Preparations are then made for moving the building. This is effected by placing on the

cribs sliding-timbers of pine, 8 inches by 10 inches, parallel with the direction in which the building has to be moved. These timbers are planed on the surface, and are wedged up perfectly level, and well greased with tallow and Castile soap. On the top of these timbers are placed boards of white oak, 1 inch thick, also planed on the surface and well greased; white oak blocks, 4 inches by 12 inches, are then inserted between the sills and the slide-boards, and pine wedges are driven between the sills and the blocks (Fig. 4). This work must be done thoroughly and with great care. The slide-timbers are in as long lengths as can be obtained, and are made continuous by bolting planks on each side at the joints; they are prolonged to the new site destined to be occupied by the building, and are securely supported for the whole distance on cribwork, or on sleepers firmly bedded in the ground. The screws are then slowly slackened and removed, leaving the entire weight of the building on the slide-timbers.

The screws for moving the building are now placed in position, with the head of the screw abutting against the ends of the longitudinal sills, and the foot of the log bearing against a firm foundation built in the ground, which is placed about 12 inches lower than at the sill. Twelve of these screws were employed to move the building described, and were put in the position shown in Figs. 1b and 2b. All the screws were advanced simultaneously when the signal was given, and the building was propelled at a rate of about 1¼ foot per hour until it reached the site it now occupies. Crib-work was rebuilt around the walls, and the screws were set in position in the same manner as at the commencement of the work. The load was taken off the slides, which were then removed; the permanent foundations were built and wedged up between the needles; the weight of the building was then slowly and gradually transferred to the new masonry; the needle beams were withdrawn, and the space which each had occupied was carefully built up.

In moving a brick cottage, the method adopted was substantially the same as in the preceding example; but, instead of being moved in a straight line, the building was turned partially round. On plan, the building is irregular in form, about 28 feet wide by 70 feet deep. It is two stories high, and includes a tower 12 feet square by three stories high. The exterior walls are all faced with pressed brick. The building was moved before the erection had been completed; but the walls were built, the floors laid, and the roof was finished. Needle-beams were inserted through the foundation walls, and the building was raised about 1 inch, just

sufficient to take all the weight on the screws, after which the necessary preparations were made, the slide-timbers laid secure and firm, and the moving screws fixed in position. The rear part of the building was turned by advancing the screw at this point further than the rest. The screw at the front of the building remained stationary, and the intermediate screws were moved through a proportionate distance. This operation was continued until the rear had been moved a distance of 15 feet, while the front had not been advanced. Subsequently the building was transferred bodily 30 feet. The work of raising and moving the building, and of building the foundations at the new site, took fifty days. One hundred and fifty screws were used to raise and lower the structure, twenty screws were required to move it, and the rate of progress did not exceed 4 feet per day. The weather was dry, hot and dusty; the grease was in an almost fluid condition, and it was found impossible to keep the sliding surfaces clean and free from sand, which was continually blown on them. The sliding surfaces were pine on pine, and the friction between them was very great; consequently progress was slow. The method adopted for moving in this case was unusual. Generally, when a building has to be turned or transported in any but a straight line, it is propelled on rollers, which can be steered in any direction, and are easily managed. The rollers are of maple, 8 inches in diameter, and occupy the place of the slides.

When other buildings abut against the one to be shifted, the cribwork outside the walls must be omitted, and the building raised and moved from the inside, as shown in Fig. 7. The needle beams are in long lengths spanning the width of the building, and spaced about 2 feet apart. The load rests on the ends which overhang the cribwork, and supports are also built on the needles to the floor joists, which are in this manner utilized to carry part of the weight. During the widening of State-street, in the City of Chicago, from 80 to 100 feet, for a distance of over 3 miles in length, several brick buildings, three and four stories high, were transplanted in this manner.

One building was set back 4 feet without the aid of screws (Fig. 8). Holes 4 feet long and 4 feet apart were cut through the walls; the bottoms of the openings were made level, and sliding-timbers, well greased, were inserted in the middle of the walls and firmly wedged with pine. The intermediate parts of the wall were next cut out, and sections of the lower sliding-timbers fitted between those already inserted and levelled. The building was then moved in the usual manner to the distance desired, bringing

the upper slides over the adjoining lower ones; the loose timbers were taken out, and the openings closed with masonry and wedged; finally the slide-timbers were removed, and the underpinning was completed.

The placing of the slide-timbers on the foundation in the centre of the wall is rarely practised, since the cribwork being already built, and its strength and firmness demonstrated by supporting the building on screws, it is advisable to take advantage of it for supporting the slides; moreover, a larger friction-surface is presented by adopting four sliding-timbers in place of one, and a broad base is secured for the wall while moving. The work progresses more smoothly and safely, and the expense of cutting and preparing a level surface on the masonry foundation is saved.

In the adoption of the ordinary screw for moving, a great part of the time is occupied in fleeting and building out the cribs at the foot. To overcome this objection, Mr. Hollingsworth has designed a screw (Fig. 9) of steel, 3 inches in diameter and 8 feet long; it is divided in the centre of the length by a boss for turning; on one side of the centre the thread is right-handed, and on the opposite side left-handed. The nuts are similar to those on the common screw, set in the ends of pine logs 8 inches by 8 inches; the logs are bored out their whole length to allow the screw to work freely through them. To hold the foot of the log, the lower slide-timber is prolonged beyond the building, and a cast-iron foot-block is secured by a strap to it. By this screw the building is propelled 6 feet before fleeting, whereas, with the ordinary screw, the change has to be made every 16 inches.

The method of prolonging the slide-timber, to resist the pressure of the moving screw, was at one time generally adopted, and is still practised occasionally; it is objectionable on account of the liability of drawing the slides from under the building, and contractors prefer a foundation for the moving screw independent of the structure, and think it far safer.

The Author is indebted to Mr. E. F. Bosley and Messrs. Hollingsworth and Conglin for information and assistance in preparing this Paper. It is illustrated by several diagrams, from which Plate 9 has been prepared.

(*Paper No. 1922.*)

"Account of some further Tests of Riveted Joints of Steel Plates for Boiler-work."

By Charles Henry Moberly, M. Inst. C.E.

This account may be considered as a sequel to a former one, communicated by the Author to the Institution.[1] It consists of two separate parts, the first dealing with tests of $\frac{7}{16}$-inch-plate joints, and the second with those of $\frac{5}{16}$-inch-plate joints, followed by a comparison of all the results obtained and conclusions from them. In each case the joints were designed for actual work, which was carried out.

The plates were all of Landore S quality, and the rivets were supplied by the Landore works, of their best rivet quality. The plates were all punched, and not annealed after punching. The rivet-holes were carefully set out and punched, and their diameter measured with a taper steel gauge, graduated on its edge.

Part I.—$\frac{7}{16}$-inch-plate joints.

The test specimens were marked A, B, C, D, E, F, G, and H; the first six were cut from one plate; the last two, which were prepared for shearing the rivets, were cut from another plate.

The rivets were $\frac{3}{4}$ inch nominal diameter, and they were riveted in a hydraulic riveting machine, with a pressure of 25 tons in the accumulator placed next to it.

The tests were all made by Mr. D. Kirkaldy, and the particulars are given in his reports of the 22nd of May, 1882, for the joints, and the 23rd of May for the plates and rivets, both of which are appended to this Paper. By the report of the 22nd of May it was found that Mr. Kirkaldy's measurements of the lap and distance between the rows of rivet-holes differed in some cases from those taken by the Author. The Author has adhered to his own measurements, and corrected that of the distance between the rows of holes in the copy of the report appended to this Paper.

[1] "Account of some Tests of Riveted Joints for Boilerwork." Minutes of Proceedings Inst. C.E., vol. lxix. (1882), p. 337.

The following data were deduced from the tests of the $\frac{9}{16}$-inch plate-joints, and used in proportioning the first of the present specimens:—

		Tons.
Strength of solid plate, per square inch	=	30·0
„ plate on straight line, through holes		28·5
„ „ zigzag „ „ „		24·0

Shearing strength of rivets = 24 tons per square inch.

The first two joints, A and B, were proportioned as shown in Fig. 1, each exactly three pitches ($8\frac{1}{4}$ inches) broad.

It will be convenient at once to designate the principal elements of the joints by distinctive letters, thus:—

Pitch of rivets along straight line	$= P$
„ „ zigzag „	$= P_1$
Distance between the holes, along straight line	$= l$
„ „ „ „ zigzag „	$= l_1$
„ „ centre lines of rivet holes	$= m$
Lap	$= L$
Margin, or distance from centre line of rivets to edge	$= \mu$
Mean diameter of rivet holes	$= d$
Small „ or shearing diameter of rivets	$= d_1$
Shearing area of one rivet	$= a$
Bearing surface of one rivet on the plate	$= a_1$

In A and B the dimensions are as follow:—

$P = 2·75$ inches; $P_1 = 1·944$ inch; $l - 1·907$ inch; $l_1 = 1·101$ inch;
$m = 1·375$ „ $L = 3·75$ inches $\mu = 1·19$ „ $d = 0·843$ „
$d_1 = 0·808$ „ $a = 0·513$ square inch; $a_1 = 0·37$ square inch.

The calculated strength of the joint for one pitch was—

			Tons.
Solid plate	$= 2·75 \times \frac{7}{16} \times 30$	=	36·1
Through holes, straight line	$= 1·907 \times \frac{7}{16} \times 28·5$	=	23·78
	=65·87 per cent. of solid plate.		
„ „ zigzag „	$= 2·202 \times \frac{7}{16} \times 24$	=	23·12
	=64·0 per cent. of solid plate.		
Shearing two rivets	$= 2 \times 0·513 \times 24$	=	24·62
	=68·2 per cent. of solid plate.		

The particulars of these specimens and their fractures are shown in Fig. 2. A broke with 65·78 tons, through the rivet-holes along the zigzag line, in one plate only; B broke with 66·12 tons, also through the rivet-holes along the zigzag line, but partly in each of the plates, namely, in one plate from one side up to the fifth rivet-hole, and thence to the other side in the

other plate. But this fracture may fairly be considered as if it had taken place all in one plate, as in A.

Taking these two joints together, the mean breaking-load was 65·95 tons, the thickness of plates 0·44 inch, and the breaking-strength of the plates 28·2 tons per square inch.

The strains on the different parts were:—

		Tons per Square inch.	Per cent.
On section of solid plate . .	$=\frac{65\cdot95}{3\cdot63}$	$=18\cdot17$	$=64\cdot42$ of breaking-strength.
„ straight line through holes	$=\frac{65\cdot95}{2\cdot517}$	$=26\cdot2$	$=92\cdot9$ of solid plate.
„ zigzag „ „ „	$=\frac{65\cdot95}{2\cdot9}$	$=22\cdot74$	$=80\cdot63$ „ „
To shear rivets	$=\frac{65\cdot95}{3\cdot078}$	$=21\cdot42$	$=72\cdot12$ of tensile strength.
On bearing surface . . .	$=\frac{65\cdot95}{2\cdot22}$	$=29\cdot7$	

To prevent fracture along the zigzag line, the next two specimens, C and D, were prepared with increased distance (m) between the rows of rivets, and increased lap (L) thus:—

$P = 2\cdot75$ inches; $l = 1\cdot907$ inch; and section along $l = 0\cdot839$ square inch
$P_1 = 2\cdot083$ „ $l_1 = 1\cdot24$ „ „ „ $2\,l_1 = 1\cdot09$ „ „
$L = 4\cdot0$ „ $\mu = 1\cdot219$ „ and $m = 1\frac{9}{16}$ inch $= 1\cdot5625$ inch.

The rivets and holes remained as before. C broke with 66·5 tons, by tearing through the rivet-holes along the straight line, partly in one plate and partly in the other, as shown in Fig. 3, the fracture in one plate opening $\frac{5}{8}$ inch at the side, and in the other plate $\frac{1}{4}$ inch. This may be considered equivalent to a fracture along the straight line in one plate only. The thickness of the plate was 0·44 inch, and its breaking-strength 28 tons per square inch. The strains on the several parts were:—

		Tons per Square inch.	Per cent.
On section of solid plate . .	$=\frac{66\cdot5}{3\cdot63}$	$=18\cdot32$	$=65\cdot4$ of breaking-strength.
„ straight line through holes	$=\frac{66\cdot5}{2\cdot517}$	$=26\cdot42$	$=94\cdot357$ of solid plate.
„ zigzag „ „ „	$=\frac{66\cdot5}{3\cdot27}$	$=20\cdot336$	$=72\cdot63$ „ „
To shear rivets	$=\frac{66\cdot5}{3\cdot078}$	$=21\cdot6$	$=72\cdot72$ of tensile strength.
On bearing-surface . . .	$=\frac{66\cdot5}{2\cdot22}$	$=29\cdot95$	

D broke with 65·3 tons, by tearing through the rivet-holes along the straight line the whole way across, and also diagonally between the two last holes on one side, and again from the last hole to the side, all in one plate, as shown in Fig. 4. The fracture was granular throughout, the strength of the plate being 28·8 tons per square inch, and its thickness 0·44 inch. The test-strips which gave this tensile strength broke with a silky fracture, but with considerably less contraction of area and extension than any other specimens of the series, showing that the plate from which all the joints were cut was not quite uniform, and that that portion from which this joint was cut was more granular than the rest. It is therefore probable that it would be weakened by punching more than the other plates, which were more silky in texture. And hence it is perhaps hardly fair to use this joint in a comparison with the others. The strains on the several parts were:—

		Tons per Square inch.	Per cent.
On section of solid plate	$= \frac{65\cdot3}{3\cdot63}$	$= 17\cdot99$	$= 62\cdot46$ of breaking-strength.
„ straight line through holes	$= \frac{65\cdot3}{2\cdot517}$	$= 25\cdot94$	$= 90\cdot0$ of solid plate.
„ zigzag „ „	$= \frac{65\cdot3}{3\cdot27}$	$= 20\cdot0$	$= 69\cdot44$ „ „
To shear rivets	$= \frac{65\cdot3}{3\cdot078}$	$= 21\cdot21$	$= 71\cdot41$ of tensile strength.
On bearing-surface	$= \frac{65\cdot3}{2\cdot22}$	$= 29\cdot41$	

Carrying out the suggestion made in the account of tests of $\frac{9}{16}$-inch-plate joints, the next two joints, E and F, were made exactly like the last two in every respect, except that they were made one pitch wider, namely 11 inches, or four pitches, instead of $8\frac{1}{4}$ inches, or three pitches wide.

E yielded with 92·4 tons, by shearing six rivets and tearing out from the rivet-hole at one corner in each plate, as shown in Fig. 5, which also illustrates the complete specimen joint. The strength of the plate was 28·9 tons per square inch, and its thickness 0·44 inch.

F yielded with 92·1 tons, by breaking through four rivet-holes from one side along the zigzag line in one plate, and through one rivet-hole from the other side along the straight line in the other plate, as shown in Fig. 6. The strength of the plate was 28·7 tons per square inch, and its thickness 0·44 inch.

Taking these two joints together, their mean breaking-strength was 92·25 tons, and of the plates 28·8 tons per square inch.

The strains on the several parts were :—

		Tons per Square inch.	Per cent.
On section of solid plate . .	$= \frac{92 \cdot 25}{4 \cdot 84}$	$= 19 \cdot 06$	$= 66 \cdot 18$ of breaking-strength.
„ straight line through holes	$= \frac{92 \cdot 25}{3 \cdot 356}$	$= 27 \cdot 49$	$= 95 \cdot 45$ of solid plate.
„ zigzag „ „ „	$= \frac{92 \cdot 25}{4 \cdot 36}$	$= 21 \cdot 15$	$= 73 \cdot 42$ „ „
To shear rivets	$= \frac{92 \cdot 25}{4 \cdot 104}$	$= 22 \cdot 48$	$= 75 \cdot 7$ „ „
On bearing-surface . . .	$= \frac{92 \cdot 25}{2 \cdot 968}$	$= 31 \cdot 08$	

Lastly, two specimens, G and H, were prepared to determine the shearing strength of the rivets. They were made 17 inches wide, and were marked out for six pitches of the same proportions as C, D, E, and F, but had only six holes and rivets put in, as shown in Fig. 7.

The rivets were sheared in both cases, in G with 80 tons and in H with 79·9 tons, or a mean of 79·95 tons. The area of six rivets sheared was 3·078 square inches, and the mean tensile strength of the six rivets tested (report of 23rd of May) was 29·7 tons per square inch. The result was thus :—

		Tons per Square inch.	Per cent.
Shearing strength of rivets	$= \frac{79 \cdot 95}{3 \cdot 078}$	$= 25 \cdot 97$	$= 87 \cdot 44$ of their tensile strength.

It should here be stated that the rivets were made red hot, and then allowed to cool, before being prepared for testing for tensile strength, so as to put the metal, as far as practicable, into a similar condition to that in the rivets in the joints, or at any rate to ensure a more uniform result than was obtained on previous occasions, when the rivets to be tested were not first heated. Notwithstanding this precaution, the results of the tensile tests were far from uniform. Although, therefore, the mean tensile strength of the rivets tested was as high as 29·7 tons per square inch, and the shearing strength 87·44 per cent. of this, it would not be prudent to allow quite so much for the rivets in designing a joint.

For the reason already given, joint D cannot be used to compare with the others for the purpose of deducing conclusions.

Comparing the others, the following is the general result :—

A and B broke through the rivet-holes along the zigzag line, showing a strength per square inch of original section equal to 80·63 per cent. of the solid plate.

C broke through the rivet-holes along the straight line, showing

a strength per square inch of original section equal to 94·357 per cent. of the solid plate.

E broke by shearing all the rivets except two, and by tearing out the corners of the plates.

F broke through the rivet-holes, partly along the straight line, but chiefly along the zigzaz line.

It is fair to conclude that the proportions of the joints C, E, and F were such that their strength was the same to resist yielding, either by shearing the rivets or by breaking through the rivet-holes along the straight or zigzag lines. It must, however, be remarked that the rivets in E were sheared with, apparently, decidedly less strain than those in G and H. This will be explained further on, in connection with joint D of the $\frac{5}{16}$-inch series.

As E and F had one pitch more than C, the difference between the strength of the two should be the strength of one pitch. But as the solid plate of C broke with 28 tons per square inch, and that of E and F with 28·8 tons, the total breaking-strain of C must be increased as 28 to 28·8, in order to compare fairly with E and F. This brings it up to $\frac{28 \cdot 8}{28} \times 66 \cdot 5 = 68 \cdot 4$ tons.

The strength per pitch becomes then—

$$82 \cdot 25 \text{ tons} - 68 \cdot 4 \text{ tons} = 23 \cdot 85 \text{ tons.}$$

The sectional area of the solid plate per pitch is $2 \cdot 75 \times 0 \cdot 44 = 1 \cdot 21$ square inch; hence the strength of the joint $= \frac{23 \cdot 85 \times 100}{1 \cdot 21 \times 28 \cdot 8} = 68 \cdot 44$ per cent. of the solid plate.

The results may now be tabulated as follows:—

Joints.	A and B.	C.	D.	E and F.	Computed Mean.	G and H.
Ultimate strength of plates and rivets . . tons per square inch	28·2	28·0	28·8	28·8	28·8	29·7
Breaking-stress on gross section of joint . tons per square inch	18·17	18·32	17·99	19·06	19·71	..
Strength of joint, percentage of solid plate	64·42	65·4	62·46	66·18	68·44	..
Breaking-stress along straight line . . tons per square inch	26·2	26·42	25·94	27·49	28·42	..
Being per cent. of solid plate	92·9	94·36	90·0	95·45	98·68	..
Breaking-stress along zigzag line tons per square inch	22·74	20·34	20·0	21·15	21·88	..
Being per cent. of solid plate	80·63	72·63	69·44	73·42	76·0	..
Shearing-stress on rivets, tons per square inch	21·42	21·6	21·21	22·48	23·25	25·97
Being per cent. of tensile strength	72·12	72·72	71·41	75·7	78·28	87·44
Bearing-pressure on rivets, tons per square inch	29·64	29·95	29·41	31·08	32·14	35·93

The last column but one, headed computed mean, is computed from the strength per pitch = 23·85 tons, being the difference between the breaking-load of E and F and that of C, as already explained. Taking this strength per pitch, E and F ought to have broken with $4 \times 23 \cdot 85 = 95 \cdot 4$ tons each, instead of the actual breaking-stress of 92·25 tons. The difference, 3·15 tons, is the loss of strength due to the weakening of the sides by the proximity of the holes to the edges, which causes fracture to commence there. This is clearly demonstrated by the fractures of B, C, and F, in each of which cases the plates were fractured, and the parts more or less separated at the edges, whilst they still hung together towards the middle of the joint. It follows, therefore, that the strength of the joint, and of the plate in the joint, as computed and given in the column headed "Computed Mean," should in every case be greater than that derived from any tests of specimens with uniform widths; and that results with such specimens should approximate more closely to the computed ones as the width of the specimen is increased. This, it will be seen, is the case with the strength of the joints, and the strength of the plate in the joints along the straight line through the rivet-holes. But it is not the case with the strength of the plate along the zigzag line of fracture. Here another variable condition exists, which affects the result, namely, the distance between the rows of rivets, which determines the angle of the zigzag line with the straight line, or the ratio $\frac{p}{m}$ between the pitch and the distance between the rows of holes. In A and B, $\frac{p}{m} = \frac{2\frac{3}{4}}{1\frac{3}{8}} = 2$, and in the other joints $\frac{p}{m} = \frac{2\frac{3}{4}}{1\frac{9}{16}} = 1 \cdot 76$, whilst the strength of the plate along the zigzag line of fracture was 80·63 per cent. of the solid plate in A and B, and only 73 per cent. in C, E, and F. This shows a diminution of strength along the zigzag line, with a decrease of the ratio $\frac{p}{m}$. This point will be dealt with in the concluding examination of all the results.

The Figs. 1 to 7 show the way in which the several joints broke, how they were bent back in the width of the lap by the breaking-stress, and also the mode of attachment of each specimen to the testing-machine. The elongation of the pin-holes was very small, but slightly greater in the holes nearest the joint than in those further back. The bearing-pressure in these pin-holes was as follows:—

In A and B	21·4	tons per square inch,	holes slightly elongated.					
„ C „ D	21·4	„	„	„	„	„		
„ E „ F	23·3	„	„	„	„	„		
„ G „ H	20·19	„	„	„	hardly perceptibly elongated.			

PART II.—$\frac{5}{16}$-INCH-PLATE JOINTS.

There were six test specimens, marked A, B, C, D, E, and F, the first four being cut from one plate, and the last two, for shearing-test of the rivets, from another plate.

The rivets were $\frac{5}{8}$-inch nominal diameter, and were riveted in the same manner as the previous joints, but with an accumulator-pressure of 20 tons only. The tests were made by Mr. D. Kirkaldy, as before, and the particulars are given in his reports of the 8th of September, 1882, for the joints, and the 9th of September for the plates and rivets, both appended to this Paper.

The joints were designed before those with $\frac{7}{16}$-inch plates had been tested, and the same data were, therefore, used in proportioning them. Using the same notation as before:

$P = 2·5$ inches; $P_1 = 1·905$ inch; $l = 1·81$ inch; $l_1 = 1·215$ inch;
$m = 1\frac{7}{16} = 1·4375$ inch; $L = 3·5$ inches; $\mu = 1·03125$ inch; $d = 0·69$ inch;
$d_1 = 0·66$ inch; $a = 0·342$ square inch; $a_1 = 0·22$ square inch.

The thickness of all the plates was 0·32 inch. These particulars are shown in Fig. 8.

The estimated strains per pitch, for an ultimate tensile strength of the plates of 30 tons per square inch, and an ultimate shearing strength of the rivets, of 24 tons per square inch, were:—

			Tons.
Solid plate	$= 2·5 \times 0·32 \times 30·0$	=	24·0
Through holes, in straight line	$= 1·81 \times 0·32 \times 28·5$	=	16·5
„ zigzag „	$= 2·43 \times 0·32 \times 24·0$	=	18·66
Shearing two rivets	$= 2·0 \times 0·342 \times 24·0$	=	16·42

Making the strength of the joint $= \frac{16·42 \times 100}{24} = 68·4$ per cent. of the solid plate.

It will be convenient to consider the tests of the rivets first. The tensile tests are given in Mr. Kirkaldy's report of the 9th of September, 1882.

The six rivets tested were first heated and then allowed to cool, as explained in connection with the rivets for the $\frac{7}{16}$-inch joints. These rivets proved more uniform in strength than the former ones, as well as stronger. Their mean tensile strength was 32·6 tons per square inch.

The shearing strength is shown by the tests of joints E and F (Mr. Kirkaldy's report of the 8th of September, and Fig. 9).

E broke with 58·5 tons, and F with 55·6 tons, giving a mean of 57·05 tons for six rivets, or $\frac{57 \cdot 05}{2 \cdot 052} = 27 \cdot 8$ tons per square inch, equal to $\frac{2{,}780}{32 \cdot 6} = 85 \cdot 27$ per cent. of their tensile strength. The bearing-pressure was $\frac{57 \cdot 05}{1 \cdot 32} = 43 \cdot 22$ tons per square inch.

The first two joints, A and B, were made 7½ inches, or three pitches, wide, and are shown in Fig. 10. They both broke in the same way, along the straight line, through the rivet-holes of one row, then diagonally to the third rivet-hole in the other row, and thence to the side of the joint. The section along the straight line, from the last rivet-hole in the first row to the side of the joint, is greater than that along the actual line of fracture, passing through the last rivet-hole in the second row; hence the deviation of the fracture from the straight line.

A broke with 50·7 tons, the strength of the plate being 28·8 tons per square inch; and B broke with 51·2 tons, the strength of the plate being 29·3 tons per square inch. The mean of these gives a breaking-load of 50·95 tons, or 16·98 tons per pitch, for a strength of plate of 29·05 tons per square inch, and the strains on the several parts become—

		Tons per Square Inch.	Per cent.
On section of solid plate . .	$= \frac{50 \cdot 95}{2 \cdot 4}$	$= 21 \cdot 23 =$	73·08 of breaking-strength.
„ straight line, through holes	$= \frac{50 \cdot 95}{1 \cdot 7376}$	$= 29 \cdot 31 =$	100·89 of solid plate.
„ zigzag „ „ „	$= \frac{50 \cdot 95}{2 \cdot 33}$	$= 21 \cdot 87 =$	75·28 „ „
To shear rivets	$= \frac{50 \cdot 95}{2 \cdot 052}$	$= 24 \cdot 83 =$	76·16 „ „
On bearing-surface . . .	$= \frac{50 \cdot 95}{1 \cdot 32}$	$= 38 \cdot 6$	

The next two joints, C and D, were made of the same proportions as A and B, but 10 inches wide, or one pitch wider, as shown in Fig. 11.

C broke as shown in Fig. 11 with 68 tons, in exactly the same way as A and B, whereas D broke with 70·8 tons, by both plates tearing out from the corner rivets, and by shearing the remaining six rivets, as shown in Fig. 12, exactly in the same way as joint E of the $\frac{7}{16}$-inch series.

An examination of the strength of the test-strips, cut from the plates of these joints, given in the report of the 9th of September,

shows that D was stronger than C; but the metal was less ductile, as the contraction of area and the extension were both less than in C. Hence, while the actual breaking-strain on D was greater than on C, the want of ductility in the former probably caused the fracture to begin with the tearing out of the corners of the plate, the whole of the strain then coming on six remaining rivets and the remaining plate-area. The rivets, being then the weakest part of the joint left, would be sheared. Of course the shearing-stress per square inch of rivet-area, taken on the whole of the eight rivets, comes out less than that obtained from the tests of E and F. On the whole, it seems fair to use the mean result of the tests of C and D to compare with A and B. This mean gives the breaking-load for C and D equal to 69·4 tons, or 17·35 tons per pitch, for a strength of plate of 29·3 tons per square inch.

The strains on the several parts came out:—

		Tons per Square inch.	Per cent.	
On section or solid plate . .	$=\dfrac{69{\cdot}4}{3{\cdot}2}$	$=21{\cdot}68=$	74·0	of breaking-strength
„ straight line, through holes	$=\dfrac{69{\cdot}4}{2{\cdot}317}$	$=29{\cdot}95=$	102·22	of solid plate.
„ zigzag „ „ „	$=\dfrac{69{\cdot}4}{3{\cdot}11}$	$=22{\cdot}31=$	76·14	„ „
To shear rivets	$=\dfrac{69{\cdot}4}{2{\cdot}736}$	$=25{\cdot}36=$	77·79	„ „
On bearing-surface	$=\dfrac{69{\cdot}4}{1{\cdot}76}$	$=39{\cdot}43$		

To arrive at the strength of the joint by comparing A and B with C and D, the breaking strain of A and B must be augmented in the ratio of the strength of the plates in A and B to that of those in C and D, *i.e.*, as 29·05 : 29·3, which brings it up to $\dfrac{50{\cdot}95\times 29{\cdot}3}{29{\cdot}05}=51{\cdot}39$ tons. Deducting this from the mean breaking-strength of C and D leaves $69{\cdot}4-51{\cdot}39=$ say 18 tons as the breaking strength per pitch of the joint.

This corresponds to the following strains on the several parts:—

		Tons per Square inch.	Per cent.	
On section of solid plate . .	$=\dfrac{18}{0{\cdot}8}$	$=22{\cdot}5=$	76·79	of breaking-strength.
„ straight line, through holes	$=\dfrac{18}{0{\cdot}579}$	$=31{\cdot}08=$	106·1	of solid plate.
„ zigzag „ „ „	$=\dfrac{18}{0{\cdot}78}$	$=23{\cdot}07=$	78·76	„ „
To shear rivets	$=\dfrac{18}{0{\cdot}684}$	$=26{\cdot}31=$	80·7	of tensile strength.
On bearing-surface	$=\dfrac{18}{0{\cdot}44}$	$=40{\cdot}9$		

The results may now be tabulated thus:—

Joints.	A and B.	C and D.	Computed Mean.	E and F.
Ultimate strength of plates and rivets tons per square inch	29·05	29·3	29·3	32·6
Breaking-stress on gross section of joint . . . tons per square inch	21·23	21·68	22·5	..
Strength of joint, percentage of solid plate	73·08	74·0	76·79	..
Breaking-stress along straight line tons per square inch	29·31	29·95	31·08	..
Being per cent. of solid plate .	100·89	102·22	106·1	..
Breaking-stress along zigzag line tons per square inch	21·87	22·31	23·07	..
Being per cent. of solid plate .	75·28	76·14	78·76	..
Shearing-stress on rivets . tons per square inch	24·83	25·36	26·31	27·8
Being per cent. of tensile strength	76·16	77·79	80·7	85·27
Bearing-pressure on rivets . tons per square inch	38·6	39·43	40·0	43·22

The column headed "Computed Mean" is computed from the difference between A and B, and C and D, in the same way as in the case of the $\frac{7}{16}$-inch joints.

On comparing the results here given with the data in Mr. Kirkaldy's report of the 8th of September, it will be seen that he takes the diameter of the rivets at 0·68 inch, with an area of 0·363 square inch, whereas the diameter here given is 0·66 inch, with an area of 0·342 square inch. Mr. Kirkaldy probably measured some of the rivets in the pieces cut out of the joints in shaping them, whereas the Author measured the holes before riveting. The rivets, doubtless, swelled up slightly in riveting, so that Mr. Kirkaldy's measurement may be the more correct of the two; but the Author prefers adhering to the plan he has followed throughout, of using the original dimensions of the plates before riveting.

The Figures 8 to 12 show the way in which the several joints broke, how they were bent back in the width of the lap by the breaking-stress, and also the mode of attachment of each specimen to the testing-machine. The elongation of the pin-holes was very slight, and always more in the holes nearest the joint than in those farther back. The bearing-pressure on these pin-holes was—

	Tons per Square Inch.	
In A and B . .	17·69	elongation in holes hardly perceptible.
„ C and D . .	24·1	„ „ slight.
„ E and F . .	19·89	„ „ hardly perceptible.

A comparison may now be made between the results of the tests

of the $\frac{9}{16}$-inch plate-joints of the former Paper, and those of the $\frac{7}{16}$-inch and $\frac{5}{16}$-inch plate-joints of the present one, bearing in mind that the conclusions arrived at are only applicable to plates and rivets similar to those used in the experiments. The strength of the plates was very uniform, from 28 to 30 tons per square inch. The strength of the rivets was not by any means so uniform, their mean tensile strength varying from 29 to 32·6 tons per square inch, whilst their shearing-strength, derived from these means, was from 84·82 per cent. to 87·44 per cent. of the tensile strength.

The conclusions may therefore be considered applicable to mild steel plates from $\frac{5}{16}$-inch to $\frac{9}{16}$-inch in thickness, having a tensile strength of from 28 to 30 tons per square inch, with a contraction of fractured area of 45 to 55 per cent., and an elongation in 10 inches of 23 to 30 per cent.; and to steel rivets having a tensile strength of 28 to 32 tons per square inch, and a shearing-strength of about 85 per cent. of their tensile strength, or say of 25 tons per square inch.

For the purpose of comparison, the results are now summarised as follows. (See next page.)

An examination of these results leads to the following conclusions:—

1. The strength of the metal in the joint is greater along the straight line than along the zigzag line, through the holes. This is apparent in every case. Where the breaking-strength was not ascertained, it is given as being greater (>) than the actual stress which the metal sustained.

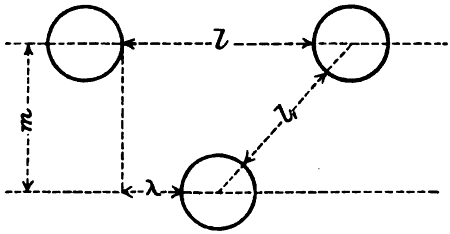
2. By increasing the distance (m) between the rows of rivets, thereby diminishing the value of $\frac{p}{m}$, the strength of the section of metal along the zigzag line to resist rupture is diminished. This does not appear as clearly as the previous conclusion, because this point was not kept in view in the $\frac{9}{16}$-inch-plate experiments, and they do not therefore afford means of direct comparison. The results of A and B, in the third column, stand by themselves for this purpose, because the holes were punched in them, whereas in K, L, O, and P they were drilled. K and L would have compared with O and P, but in K one rivet was sheared, and in L two rivets, whilst in O one rivet only was sheared, and in P none. Hence it is certain that the breaking-strength along the zigzag line was greater than the stress noted in K and L, and it is possible, if, indeed, not probable, that it would have been greater in K and L than in O and P.

But the experiments with the $\frac{7}{16}$-inch-plate joints point very

TABLE of SUMMARY of RESULTS.

Description of Joint.	$\frac{9}{16}$-inch Butt-Joints, Double-Riveted, with Double Covers, Pitch = 3·775 inches.			$\frac{7}{16}$-inch Lap-Joints, Double-Riveted, Pitch = 2·75 inches.		$\frac{5}{16}$-inch Lap-Joints, Double-Riveted, Pitch = 2·5 Inches.
Holes, how formed	Drilled		Punched			
Value of ratio $\frac{p}{m}$	2·52	2·32	2·52	2	1·76	1·74
Strength of solid plate, tons per square inch	(K and L) 30·15	(O and P) 28·9	(A and B) 29·95	(A and B) 28·2	computed mean 28·8	computed mean 29·3
" plate through rivet-holes, straight line, per cent. of solid plate	> 86·33	> 93·36	> 81·16	> 92·9	98·68	106·1
Strength of plate through rivet holes, zigzag line, per cent. of solid plate	> 80·15	82·33	77·6	80·63	76·0	78·76
Rivets, tensile strength, tons per square inch	29 ($\frac{3}{4}$-inch rivets)			29·7 ($\frac{3}{4}$-inch rivets)		($\frac{5}{8}$-in. rivets) 32·6
" shearing " " " "	24·6 (in C, F, and I)			25·97 (in G and H)		(in E & F) 27·8
Being per cent. of tensile strength	84·82			87·44		85·27
Bearing-pressure, when all rivets are sheared, tons per square inch	54·57 (in C, F, and I)			35·93 (in G and H)		(in E & F) 48·22
Bearing-pressure, when plate broke, tons per square inch	(K and L) 47·66	(O and P) 49·2	(A and B) 40·2	(A and B) 29·64	32·14	40

clearly to the conclusion stated. The stress along the diagonal or zigzag line may be assumed to be composed of a direct tensile and a shearing strain.



If p = breaking strength of plate along l per cent. of solid plate.
p_1 = " " " " l_1 " " "
s = shearing strength of plate along $m = f\,p$, also as per cent. of solid plate.

then $x = \dfrac{2\,l_1\,p_1}{2\,\lambda\,p + 2\,m\,f\,p} = \dfrac{p_1}{p} \times \dfrac{l_1}{\lambda + f\,m}$ expresses the ratio between the stress along the diagonal line and the sum of the tensile and shearing stresses of which it is assumed to be composed. The shearing-strength of the plate is assumed to bear the same proportion to its tensile strength as the shearing-strength of the rivets bears to their tensile strength, namely, say 85 per cent. Working out the ratio for the several cases gives:

For K and L ($\frac{9}{16}$-inch joints)

$l_1 = 1{\cdot}5975$ inch; $\lambda = 1{\cdot}075$ inch; $m = 1{\cdot}5$ inch

$$f = < \frac{85}{86{\cdot}33} = < 0{\cdot}98; \quad \frac{p_1}{p} = < \frac{80{\cdot}15}{86{\cdot}33} = < 0{\cdot}928$$

$$\therefore x = < 0{\cdot}928 \times \frac{1{\cdot}5975}{1{\cdot}075 + < 0{\cdot}98 \times 1{\cdot}5} \quad . = < 0{\cdot}582$$

" O and P ($\frac{9}{16}$-inch joints)

$l_1 = 1{\cdot}677$ inch; $\lambda = 1{\cdot}075$ inch; $m = 1{\cdot}625$ inch

$$f = < \frac{85}{93{\cdot}36} = < 0{\cdot}91; \quad \frac{p_1}{p} = < \frac{82{\cdot}33}{93{\cdot}36} = < 0{\cdot}88$$

$$\therefore x = < 0{\cdot}88 \times \frac{1{\cdot}679}{1{\cdot}075 + < 0{\cdot}91 \times 1{\cdot}625} \quad . = < 0{\cdot}578$$

" A and B ($\frac{9}{16}$-inch joints)

$l_1 = 1{\cdot}54$ inch; $\lambda = 1{\cdot}0175$ inch; $m = 1{\cdot}5$ inch

$$f = < \frac{85}{81{\cdot}16} = < 1{\cdot}047; \quad \frac{p_1}{p} = < \frac{77{\cdot}6}{81{\cdot}16} = < 0{\cdot}956$$

$$\therefore x = < 0{\cdot}956 \times \frac{1{\cdot}54}{1{\cdot}0175 + < 1{\cdot}047 \times 1{\cdot}5} = < 0{\cdot}568$$

For computed mean of $\frac{7}{16}$-inch joints:

$l_1 = 1\cdot24$ inch; $\lambda = 0\cdot532$ inch; $m = 1\cdot5625$ inch

$$f = \frac{85}{98\cdot68} = 0\cdot861;\ \frac{p_1}{p} = \frac{76}{98\cdot68} = 0\cdot77$$

$$\therefore x = 0\cdot77 \times \frac{1\cdot24}{0\cdot532 + 0\cdot861 \times 1\cdot5625} \quad . \quad . \quad = 0\cdot508$$

„ computed mean of $\frac{5}{16}$-inch joints:

$l_1 = 1\cdot215$ inch; $\lambda = 0\cdot56$ inch; $m = 1\cdot4375$ inch

$$f = \frac{85}{103\cdot39} = 0\cdot822;\ \frac{p_1}{p} = \frac{76\cdot8}{103\cdot39} = 0\cdot742$$

$$\therefore x = 0\cdot742 \times \frac{1\cdot215}{0\cdot56 + 0\cdot822 \times 1\cdot4375} \quad . \quad . \quad . = 0\cdot518$$

This points to the conclusion that the strength of the metal along the zigzag or diagonal line is about one-half of the sum of the direct tensile and shearing strengths into which it may be resolved.

If this be correct, a ready means is at once afforded of estimating the strength of the metal in riveted joints along the zigzag line for any arrangement of rivets. But these experiments, by themselves, are not sufficient to warrant the acceptance of this conclusion without further corroboration.

3. The strength of the metal along the straight line, through the holes, appears to increase with the reduction of the thickness of the plates. But this is somewhat mixed up with the ratio of the pitch to the thickness of plate, and it would not be safe to accept this conclusion unless corroborated by other experiments.

Meanwhile, for such joints as those under consideration, and with punched holes, it will probably be safe to assume that the strength of the metal in this direction is: for $\frac{5}{16}$-inch plates, 106 per cent.; for $\frac{7}{16}$-inch plates, 98 per cent.; and for $\frac{9}{16}$-inch plates, perhaps 90 per cent. of the strength of the solid plate, as ascertained by test-strips.

The fact that the strength of the metal in the joint is in excess of that in the solid plate, in the case of the $\frac{5}{16}$-inch plates, is in accordance with the results obtained by Professor Kennedy, in his experiments for the Institution of Mechanical Engineers, and for which he gave an explanation in his report, as published in the Proceedings of that Institution for 1881, p. 217.

4. The margin (μ) has generally been taken to be a function of the diameter of the rivet, usually equal to $1\frac{1}{2}$ diameter. But, inasmuch as the plates yielded from the rivet-holes outwards by shearing, it seems more correct to proportion the margin with reference to the distance between the rivet-holes along the straight

line. In the case of the $\frac{9}{16}$-inch joints, when $\mu = 1\cdot125$ inch, and $\frac{\mu}{l} = 0\cdot38$, the plate was sheared out from the holes to the edge; and when μ was increased to $1\cdot25$, making $\frac{\mu}{l} = 0\cdot422$, the plate was sheared out from the rivet-holes in one case only. In the case of the $\frac{7}{16}$-inch joints, with $\mu = 1\cdot1875$ inch, and $\frac{\mu}{l} = 0\cdot622$; and in the $\frac{5}{16}$-inch joints, with $\mu = 1\cdot03$ and $\frac{\mu}{l} = 0\cdot57$, the plates were not sheared out from the rivet-holes. Hence $\frac{\mu}{l}$ should be greater than $0\cdot422$ for $\frac{9}{16}$-inch plates, and probably less than $0\cdot622$ for $\frac{7}{16}$-inch plates, and less than $0\cdot57$ for $\frac{5}{16}$-inch plates. Pending further experiments, the following values for $\frac{\mu}{l}$ may be suggested for use: $0\cdot45$ for $\frac{9}{16}$-inch plates; $0\cdot5$ for $\frac{7}{16}$-inch plates, and $0\cdot55$ for $\frac{5}{16}$-inch plates. But this point is as yet very uncertain.

5. The bearing-pressure per square inch of surface on the rivets varied a good deal, and it does not appear to have borne any relation to the shearing of the rivets, or to the yielding of the joint in any other way. As far as these experiments go, it appears that it may reach over 50 tons per square inch at the moment of fracture.

6. The rivets, as already stated, were not very uniform in quality, but their tensile strength may be taken at 30 tons per square inch, whilst their shearing-strength was fully 85 per cent. of that amount. In practice it appears safe to take their shearing-strength at 25 tons per square inch.

7. The pressure in the accumulator was—

For $\frac{9}{16}$-inch double cover butt joints with $\frac{3}{4}$-inch rivets .	35 tons.
,, $\frac{7}{16}$-inch lap joints with $\frac{3}{4}$-inch rivets	25 ,,
,, $\frac{5}{16}$-inch ,, ,, ,, $\frac{5}{8}$-inch ,, ...	20 ,,

and these pressures were evidently sufficient.

8. Finally, it may be well to remark again that it must be borne in mind that the comparison here instituted is strictly between joints of the three thicknesses given, with punched holes, the plates not being annealed after punching, and being of the Landore S quality of mild steel.

The $\frac{9}{16}$-inch joints were the only ones which were also tried with drilled holes, or holes punched and drilled out, as explained in the previous Paper.

The Paper is accompanied by several diagrams, from which Plate 10 and the figures in the text have been prepared.

TABLE I.—SUMMARY of the RESULTS of EXPERIMENTS to ASCERTAIN the ELASTIC and
and SIX RIVETS, received from

Plates, all cut Lengthway.											
Specimens out of Riveted Joint.	Test No.	Thickness.	Stress. Elastic per Square Inch.	Stress. Ultimate per Square Inch.	Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per Square Inch of Fractured Area.	Extension, Set in 10 Inches. At 40,000 lbs. per Square Inch.	Extension, Set in 10 Inches. At 50,000 lbs. per Square Inch.	Extension, Set in 10 Inches. Ultimate.	Appearance of Fracture.
	Q.	Inch.	Lbs. Tons.	Lbs. Tons.	Per cent.	Per cent.	Lbs.	Per cent.	Per cent.	Per cent.	
Q 674 A	675	·44	33,700	63,360	53·1	48·1	122,271	1·49	5·27	24·1	Silky
	676	·44	33,500	61,760	54·2	51·3	126,983	2·13	5·53	22·5	„
	Mean . .		33,600=15·0	62,560=27·9	53·6	49·7	124,627	1·81	5·40	23·3	
Q 677 B	679	·44	33,600	64,390	52·1	47·1	121,853	1·88	4·73	29·0	„
	678	·44	36,400	63,240	57·5	51·3	130,025	0·48	4·25	21·2	„
	Mean . .		35,000=15·6	63,815=28·5	54·8	49·2	125,939	1·18	4·49	25·1	
Q 1,070 C	1,072	·44	34,400	63,500	54·1	51·3	130,560	1·31	5·10	25·8	„
	1,071	·44	34,700	61,860	56·0	49·2	126,255	1·15	4·58	23·1	„
	Mean . .		34,550=15·4	62,680=28·0	55·0	50·2	128,407	1·23	4·84	24·4	
Q 1,073 D	1,075	·44	36,200	65,450	55·3	27·2	89,978	1·65	3·93	16·0	„
	1,074	·44	34,100	63,810	53·4	51·6	131,812	2·15	5·18	27·9	„
	Mean . .		35,150=15·7	64,630=28·8	54·3	39·4	110,895	1·90	4·55	21·5	
Q 1,592 E	1,594	·44	34,300	64,880	52·8	47·5	123,580	0·81	4·52	26·4	„
	1,593	·44	33,200	64,720	51·2	47·8	124,182	1·49	4·58	27·2	„
	Mean . .		33,750=15·1	64,800=28·9	52·0	47·6	123,881	1·15	4·55	26·8	
Q 1,595 F	1,596	·44	33,500	64,410	52·0	44·3	115,655	0·72	4·05	25·5	„
	1,597	·44	34,200	64,370	53·1	47·5	122,610	0·90	4·91	26·3	„
	Mean . .		33,850=15·2	64,390=28·7	52·5	45·9	119,132	0·81	4·48	25·9	
	Total mean		34,316=15·3	63,812=28·5	53·8	47·0	122,147	1·35	4·72	24·5	

Messrs. EASTON and ANDERSON,

Erith Iron Works, Erith, Kent.

ULTIMATE TENSILE STRENGTH and QUALITY of the STEEL in SIX RIVETED JOINTS, Messrs. EASTON and ANDERSON.

Steel Rivets.

Nominal Size of Rivets.	Test No.	Original. Diameter.	Original. Area.	Stress. Elastic per Square Inch. Lbs.	Stress. Elastic per Square Inch. Tons.	Stress. Ultimate per Square Inch. Lbs.	Stress. Ultimate per Square Inch. Tons.	Ratio of Elastic to Ultimate.	Fractured. Diameter.	Fractured. Area.	Fractured. Difference. Area.	Fractured. Difference. Per cent.	Stress per Square Inch of Fractured Area.	Extension.	Appearance of Fracture.
	Q.	Inch trnd.	Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.	Per cent.	Inch.	Sq. Inch.			Lbs.		
{¾ in. dia.}	1,600	·504	·200	42,200		69,180		61·0	·33	·085	·115	57·5	162,776	Too short for ascertaining the extension.	Silky.
„	1,602	„	„	41,100		68,240		60·2	·31	·075	·125	62·5	181,973		„
„	1,601	„	„	38,400		67,520		56·8	·30	·071	·129	64·5	190,197		„
„	1,603	„	„	38,300		66,420		57·6	·29	·066	·134	67·0	201,272		„
„	1,604	„	„	37,500		65,380		57·3	·28	·061	·139	69·5	214,360		„
„	1,605	„	„	36,800		63,120		58·3	·27	·057	·143	71·5	221,473		„
	Mean . . .			39,050	=17·4	66,643	=29·7	58·5				65·4	195,342		

DAVID KIRKALDY.

99, Southwark Street, London, S.E., 23rd May, 1882.

TABLE II.—SUMMARY of the RESULTS of EXPERIMENTS to ASCERTAIN the ELAST
and SIX RIVETS, receive

Plates, all cut Lengthway.												
Specimens out of Riveted Joint.	Test No.	Thickness.	Stress. Elastic per Square Inch.		Stress. Ultimate per Square Inch.		Ratio of Elastic to Ultimate.	Contraction of Area at Fracture.	Stress per Square Inch of Fractured Area.	Extension, Set in 10 Inches. At 40,000 lbs. per Square Inch.	Extension, Set in 10 Inches. At 50,000 lbs. per Square Inch.	Extension, Set in 10 Inches. Ultimate.
	Q.	Inch.	Lbs.	Tons.	Lbs.	Tons.	Per cent.	Per cent.	Lbs.	Per cent.	Per cent.	Per cent.
Q 2,804 A	2,805	·33	37,600		65,730	= 29·34	57·2	50·7	133,449	1·19	4·17	25·1
	2,806	·31	35,700		63,640	= 28·41	56·0	55·0	141,419	1·53	4·89	27·3
	Mean . .		36,650	= 16·3	64,685	= 28·8	56·6	52·8	137,434	1·36	4·53	26·2
Q 2,807 B	2,808	·33	36,800		66,080	= 29·5	55·6	53·0	140,651	1·39	3·64	25·8
	2,809	·31	37,400		64,780	= 28·92	57·7	52·2	135,685	1·25	4·22	25·6
	Mean . .		37,100	= 16·5	65,430	= 29·2	56·6	52·6	138,168	1·32	3·93	25·7
Q 2,810 C	2,811	·33	37,200		66,170	= 29·54	56·2	51·6	136,902	1·31	3·48	27·9
	2,812	·31	37,500		64,390	= 28·74	58·2	56·1	146,768	1·24	4·39	27·6
	Mean . .		37,350	= 16·6	65,280	= 29·1	57·2	53·8	141,835	1·27	3·93	27·7
Q 2,813 D	2,814	·31	37,800		65,880	= 29·37	57·3	53·7	142,317	1·04	4·68	26·0
	2,815	·33	36,900		66,360	= 29·62	55·6	48·3	128,436	1·39	4·12	27·2
	Mean . .		37,350	= 16·6	66,120	= 29·5	56·4	51·0	135,376	1·21	4·40	26·6
	Total mean		37,112	= 16·5	65,379	= 29·1	56·7	52·5	138,203	1·29	4·20	26·5

Messrs. EASTON and ANDERSON,
Erith Iron Works, Erith, Kent.

ULTIMATE TENSILE STRENGTH and QUALITY of the STEEL in SIX RIVETED JOINTS, Messrs. EASTON and ANDERSON.

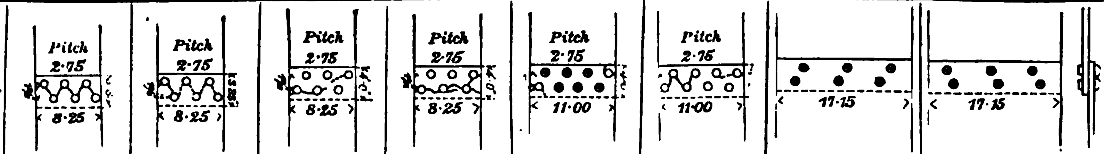
Steel Rivets.

Nominal Size of Rivets.	Test No.	Original. Diameter.	Original. Area.	Stress. Elastic per Square Inch.		Stress. Ultimate per Square Inch.		Ratio of Elastic to Ultimate.	Fractured. Diameter.	Fractured. Area.	Fractured. Difference. Area.	Fractured. Difference. Per cent.	Stress per Square Inch of Fractured Area.	Extension.	Appearance of Fracture.
	Q.	Inch trnd.	Sq. Inch.	Lbs.	Tons.	Lbs.	Tons.	Per cent.	Inch.	Sq. Inch			Lbs.		
[illegible] in. dia.	2,821	·437	·150	48,300		74,330		64·9	·29	·066	·084	56·0	168,924	Too short for ascertaining the extension.	Silky.
,,	2,820	,,	,,	48,300		74,280		65·0	·28	·061	·089	59·3	182,655		,,
,,	2,818	,,	,,	46,700		73,860		63·2	·28	·061	·089	59·3	181,622		,,
,,	2,823	,,	,,	47,100		72,710		64·7	·29	·066	·084	56·0	165,242		,,
,,	2,819	,,	,,	46,200		71,510		64·6	·28	·061	·089	59·3	175,836		,,
,,	2,822	,,	,,	44,600		71,360		62·5	·27	·057	·093	62·0	187,789		,,
	Mean . . .			46,866 =	20·9	73,008 =	32·6	64·1				58·6	177,011		

DAVID KIRKALDY.

99, *Southwark Street, London, S.E.*, 9*th September*, 1882.

TABLE V.—RESULTS of EXPERIMENTS to ASCERTAIN the ULTIMATE TENSILE STRENGTH of EIGHT RIVETED JOINTS RECEIVED from MESSRS. EASTON and ANDERSON. All Steel Plates. Nominal thickness, seven-sixteenths of an inch.

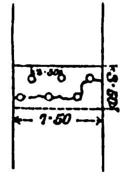
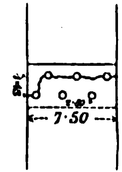
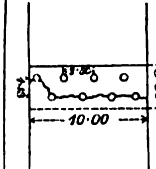
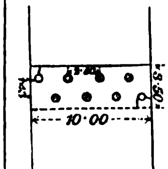
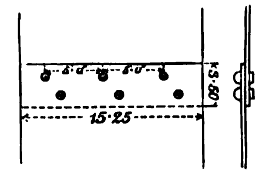


Sketch of Joint with Sizes.								
Test No., and stamped	Q 674. A.	Q 677. B.	Q 1,070. C.	Q 1,073. D.	Q 1,592. E.	Q 1,595. F.	Q 1,598. G.	Q 1,599. H.
Description of joint .	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.
Machine or hand-riveted. Rivet holes . . .	Machine. Punched.	Machine. Punched.	Machine. Punched.	Machine. Punched.	Machine. Punched.	Machine. Punched.	Machine. Punched.	Machine. Punched.
Plates. Brand.								
Plates, width and thickness.	8·25 × 0·44	8·25 × 0·44	8·25 × 0·44	8·25 × 0·44	11·00 × 0·44	11·00 × 0·44	17·15 × 0·44	17·15 × 0·44
Plates, sectional area, gross.	3·630	3·630	3·630	3·630	4·840	4·840	7·546	7·546
	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.
Stress, total . . .	147,350=65·7	148,120=66·1	149,110=66·5	146,370=65·3	207,040=92·4	206,290=92·1	179,240 = 80·0	178,980 = 79·9
Stress per square inch of gross area, joint.	40,592=18·1	40,804=18·2	41,077=18·3	40,322=18·0	42,776=19·1	42,622=19·1	23,753 = 10·6	23,718 = 10·6
Stress per square inch of plates, solid.	62,560=27·9	63,815=28·5	62,680=28·0	64,630=28·8	64,800=28·9	64,390=28·7		
Ratio of joint to solid plate, percentage.	64·8	63·9	65·5	62·3	66·0	66·2		
	64·35		63·90		66·10			
Where fractured . .	Plate at rivet holes, 100 per cent silky.	Plate at rivet holes, partly in both plates.	Plate at rivet holes, partly in both plates.	Plate at rivet holes, 5 per cent. silky, 95 per cent. granular.	Six rivets, sheared one plate at one rivet hole, the other plate at corresponding hole.	Plate at rivet holes, partly in both plates.	Six rivets, sheared simultaneously.	Six rivets, sheared simultaneously.
Rivets: diameter, area, and number.	Steel 0·81 = 0·515 × 6	Steel 0·81 = 0·515 × 6	Steel 0·81 = 0·515 × 6	Steel 0·81 = 0·515 × 6	Steel 0·81 = 0·515 × 8	Steel 0·81 = 0·515 × 8	Steel 0·81 = 0·515 × 6	Steel 0·81=0·515×6
Rivets: sectional area, total square inches.	3·090	3·090	3·090	3·090	4·120	4·120	3·090	3·090
Shearing stress per sq. inch of rivet area.	47,686=21·2	47,935=21·4	48,255=21·6	47,368=21·1	50,252=22·4	50,070=22·3	58,006 = 25·8	57,992 = 25·8
Tensile stress per sq. inch of rivet area.	66,645=29·7	66,645=29·7	66,645=29·7	66,645=29·7	66,645=29·7	66,645=29·7	66,645 = 29·7	66,645 = 29·7
Ratio of shearing to tensile, percentage.	Rivets not sheared.	Rivets not sheared.	Rivets not sheared.	Rivets not sheared.	Six rivets sheared.	Rivets not sheared.	87·0	87·0
							87·0	

Messrs. EASTON and ANDERSON, Erith Iron Works, Erith, Kent.

DAVID KIRKALDY.
99, *Southwark Street, London, S.E.*, 22nd *May*, 1882.

TABLE VI.—RESULTS of EXPERIMENTS to ASCERTAIN the ULTIMATE TENSILE STRENGTH of SIX RIVETED JOINTS RECEIVED from MESSRS. EASTON and ANDERSON. All Steel Plates. Nominal thickness, five-sixteenths of an inch.

Sketch of Joint with Sizes.						
Test No., and stamped	Q 2,804. A.	Q 2,807. B.	Q 2,810. C.	Q 2,813. D.	Q 2,816. E.	Q 2,817. F.
Description of joint	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.	Lap, double-riveted.
Machine or hand-riveted	Machine.	Machine.	Machine.	Machine.	Machine.	Machine.
Rivet holes	Punched.	Punched.	Punched.	Punched.	Punched.	Punched.
Plates. Brand.						
Plates, width and thickness.	7·50 × 0·32	7·50 × 0·32	10·00 × 0·32	10·00 × 0·32	15·25 × 0·32	15·25 × 0·32
Plates, sectional area, gross.	2·400	2·400	3·200	3·200	4·880	4·880
	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.	lbs. tons.
Stress total	113,680 = 50·7	114,860 = 51·2	152,310 = 68·0	158,670 = 70·8	131,130 = 58·5	124,720 = 55·6
Stress per square inch of gross area, joint.	47,362 = 21·1	47,858 = 21·3	47,597 = 21·2	49,854 = 22·2	26,871 = 12·0	25,557 = 11·4
Stress per square inch of plates, solid.	64,685 = 28·8	65,430 = 29·3	65,280 = 29·2	66,120 = 29·5		
Ratio of joint to solid plate, percentage.	73·22	73·14	72·91	75·39		
	73·18		74·15			
Where fractured	Plate at rivet holes, 100 per cent. silky.	Plate at rivet holes, 100 per cent. silky.	Plate at rivet holes, 100 per cent. silky.	Plate at 2 rivet holes and 6 rivets sheared.	Six rivets sheared simultaneously.	Six rivets sheared simultaneously.
Rivets: diameter, area, and number.	Steel 0·68 = 0·363 × 6	Steel 0·68 = 0·363 × 6	Steel 0·68 = 0·363 × 8	Steel 0·68 = 0·363 × 8	Steel 0·68 = 0·363 × 6	Steel 0·68 = 0·363 × 6
Rivets: sectional area, total square inches.	2·178	2·178	2·904	2·904	2·178	2·178
Shearing stress per square inch of rivet area.	52,194 = 23·3	52,736 = 23·5	52,448 = 23·4	54,638 = 24·4	60,207 = 26·9	57,263 = 25·6
Tensile stress per square inch of rivet area.	73,008 = 32·6	73,008 = 32·6	73,008 = 32·6	73,008 = 32·6	73,008 = 32·6	73,008 = 32·6
Ratio of shearing to tensile, percentage.	Rivets not sheared.	Rivets not sheared.	Rivets not sheared.	Six rivets sheared.	82·47	78·44
					80·45	

Messrs. EASTON and ANDERSON, Erith Iron Works, Erith, Kent.

DAVID KIRKALDY.
99, *Southwark Street, London, S.E., 8th Sept.*, 1882.

(*Paper No. 1943.*)

"Miners' Safety-Lamps."

By J. B. Marsaut.

(Translated and Abstracted by Alfred Bache, B.A., Assoc. Inst. C.E.)

In an elaborate essay by the engineer-in-chief of the Bessèges Collieries, Gard, in the south of France, this important subject is investigated with characteristic care, thoroughness, and discriminating fairness. Belgium having in 1864 decreed the use of a standard pattern of the Mueseler safety-lamp for her deep and fiery coalpits, the same lamp has come into extensive use in France also, after having there undergone a series of experiments at the hands of Messrs. Mallard and Le Chatelier, on behalf of the French fire-damp commission.[1] The Belgian Mueseler, which has the usual internal funnel or taper chimney of solid sheet-metal, supported above the wick by a horizontal annular diaphragm of wire-gauze, is subject to the serious inconvenience of going out when tilted; its usefulness is thereby greatly curtailed, particularly where there is any haulage on inclined planes. Ten years ago Mr. Marsaut's experiments led him to modify the Mueseler lamp, by discarding the diaphragm while retaining the chimney; a sheet-iron casing was also added outside the gauze cylinder, to prevent flame from passing outwards through it when exposed to a current of fire-damp; and a movable ring was fitted round the circle of the air-inlets, for closing them all simultaneously so as to extinguish the lamp. This lamp does not go out when tilted; does go out in fire-damp; and does not let flame pass outwards, even when exposed to strong currents of fire-damp in any direction. The only inconvenience noted by the French fire-damp commission, when recording their high commendation of the lamp, was that the sheet-iron casing prevents its being seen at a glance whether the lamp is in proper order inside the casing.

Renewing his efforts at improvement, the Author lately entered upon a further extensive series of experiments at Bessèges, of

[1] Commission du Grisou, Paris, minutes of meeting of 8th March, 1882.

which a detailed account is given. Excellent drawings are furnished of the numerous safety-lamps tried, of which the following is a bare enumeration, all being examined and commented upon in detail as to their respective merits and demerits:—the Mueseler, of Belgian and of English pattern, with several other varieties; the original Marsaut lamp of 1871, and several varieties of its present improved construction; the Davy, of Newcastle, Gard, and Dubrulle patterns, the fire-trier's, and the "tin-can"; the Stephenson, Williamson, Clanny, Bainbridge, Evan Thomas, Upton and Roberts, Birckel, Boty, Westphalian under two forms, Rosenkrantz, Combes, and Cosset-Dubrulle. Tabulated statements are given of the results obtained in the Author's trials of the various lamps; in his specially elaborate trials of the Mueseler and Marsaut lamps; in his experiments upon the resistance of wire-gauze to the passage of flame, and upon the influence of the dimensions and shape of the gauze itself; and in trials of the comparative lighting powers of the different lamps.

The practical conclusions derived from these experiments are summarised as follows. With the large Davy lamp used in the Gard district, and with other lamps of the same kind, an explosive still atmosphere outside is fired by an explosion inside the lamp. The addition of a second gauze cylinder to these lamps diminishes considerably the frequency of outside explosions, but is powerless to prevent them. The flame seems to pass out through the cap of the gauze cylinder, rather than elsewhere; whence it is well to add another layer or two of gauze at this weak part. The outside atmosphere is more readily fired by explosion within a lamp in which the wick is burning low; the prevalent practice of lowering the wick on encountering fire-damp is consequently objectionable; it is better to remove the lamp slowly, keeping the wick at its usual height. Large lamps are more dangerous than small ones, because the volume of explosive mixture they contain increases as the cube of their size, whilst the area of gauze or of outlet for the flame to pass through increases as the square only. The glass cylinder in the Mueseler and other lamps, though giving a better light, renders the explosions inside more violent, because the explosive mixture is thereby more confined, so that the lamp becomes a sort of miniature cannon; the glass should therefore be kept as small as possible, particularly in height. The Belgian Mueseler, considered the safest lamp in use hitherto, sometimes explodes a still atmosphere of fire-damp outside it. Lamps with glasses are dangerous when the wick burns low, for the same reason as the Davy; in the Mueseler particularly the flame can

then more readily pass up through the chimney, and so get to the upper side of the gauze diaphragm. The plan long in vogue at Bessèges, of ascertaining the presence of fire-damp by measuring the elongation of the lamp's full flame, is safer than reducing the flame to the utmost for the purpose of seeing the blue cap of gas better; the elongation of the flame is almost always a sufficient indication. When a glass lamp is lifted up into an explosive atmosphere, it should be held there steadily till it goes out, especially in the case of lamps having their air-inlet at the top: instead of being immediately withdrawn again, as would intuitively be done either through fear or to keep it alight; for a downward movement seems to have the effect of churning the gas inside the gauze, and so rendering its explosion more violent and thereby more dangerous. As soon as ever the gas burns very visibly in a lamp, and shows its characteristic tuft of flame, there is no fear of internal explosion occurring. It is particularly dangerous for a lamp to get suddenly filled with explosive mixture by a current blowing the flame against one side, or for the lamp itself to be tilted in such an atmosphere; any arrangement for checking undue access of gas to the lamp is a safeguard. The whole of the air-inlets should be protected by at least a double layer of wire-gauze, even in the Mueseler lamp with its chimney, which latter does not always isolate the flame; then if the inner gauze ever gets red-hot, the outer still serves as a protection. The confined space inside a lamp should be kept as small as possible; but the gauze, which cools down the gases passing out through it when the lamp explodes inside, should present as large an extent of surface as can be; hence lamps are not to be relied on which have a tall glass surmounted by a dwarf gauze, such as the big Cosset-Dubrulle, the Bainbridge, and others like them. Lamps should be made of as small diameter as possible, and should carry as large a flame as they can without getting too hot; the aim should be to make a lamp behave as much as possible like a mere chimney. In glass lamps with air-inlet at the top, the wick-holder should be tall enough to raise the flame as high as can be inside the glass; a neutral space is thus left in the bottom of the lamp, whereby the force of an explosion within the lamp is mitigated. A chimney in a lamp is attended with more or less risk. The slightest modification in form or arrangement of a lamp may make a considerable difference in its safety.

Marsaut Safety-Lamp.—In its present improved form, this lamp has a strong glass cylinder, 2·44 inches high, 1·65 inch inside diameter, and 0·31 inch thick, secured in a protecting cage on the

top of the oil reservoir, as in the Mueseler lamp; but the Mueseler chimney, and the gauze diaphragm that carries it, are done away with. Surmounting the glass cylinder, and flush with its inside circumference, is an inner gauze cylinder, 4 inches high, tapering slightly smaller upwards, and closed at the top by a gauze diaphragm. An outer gauze cylinder, about $\frac{1}{4}$ inch larger in diameter, $\frac{3}{8}$ inch taller, and similarly closed at the top, encases the inner gauze; and is fixed at the bottom into the copper ring that forms the upper rim of the cage holding the glass. The mesh of the gauze is nine hundred and thirty holes per square inch, or thirty and a half per lineal inch. The entire gauze is shielded by an external sheet-iron casing, which can be lifted off at pleasure, having inlet holes round the bottom for the air to enter the lamp, and outlet apertures at the top.

While the general shape and construction of the Mueseler lamp, as sanctioned by practice, are thus preserved in the Marsaut, the small horizontal annular diaphragm of gauze supporting the chimney in the former is replaced in the latter by the inner gauze cylinder, which presents a far larger cooling surface for the hot gases inside the lamp to pass out. Additional safety can be secured by further covering the flat top of the inner gauze cylinder with a gauze hood, so as to double the thickness of gauze at that part, upon which the force of an explosion inside the lamp comes most direct. A third complete cylinder of gauze can even be added, if desired as an extra precaution; but two are considered safe enough by the Author, and preferable generally.

The advantages of the Marsaut lamp are that it seldom goes out when tilted, and not at all in an upward current of air, nor does it explode externally a strong current of gas blowing upon it in any direction. It does not fire an explosive still mixture of air and lighting gas, as has been proved by upwards of twelve thousand trials at Bessèges, when most of the other lamps in use did so, the Belgian Mueseler included. The outside casing effectually protects the gauze from getting injured, clogged with dust, or splashed; and whenever the lamp explodes inside, the casing retards the escape of the burnt gases, which thus help to put the lamp out. By simply covering with the hand the inlet or outlet holes in the casing, the lamp can readily be put out whenever desired.

In the trials made of the Marsaut lamp at Bessèges, an explosive mixture was employed of air and of lighting gas, which latter fires more readily than fire-damp; and the wick being reduced below its usual flame, the conditions were thus more trying than

are met with underground. With three forms of the Marsaut lamp, testing two lamps of each form, upwards of six thousand trials failed to produce a single external explosion; whereas fifteen Belgian Mueselers, tested simultaneously, each of them about a hundred times over, let the flame pass through the horizontal gauze diaphragm in 31 per cent. of the trials, and in 2½ per cent. produced explosion outside the lamp.

Still severer trials were also made, by mixing air with lighting gas in their most highly explosive proportions, namely 100 volumes of air to 20 volumes of gas, and exploding the still mixture inside the lamps by an electric spark. Under this excessive test, the large Davy lamp used in the Gard district exploded the mixture outside it every time; the Boty, Clanny, and Belgian Mueseler, and the Marsaut lamp with two gauze cylinders, almost every time; but twelve trials of the Marsaut with three gauzes, and ten of the fire-trier's Davy, gave not a single explosion outside. These tests, and those preceding, point unmistakably to the desirability of reducing to the utmost both the total internal volume of a safety-lamp, and also the height of the glass, since the blind space enclosed by the glass acts like a cannon in propelling the inside explosion violently against the gauze, and so driving the flame out through it. The great effect of the height of the wick in the glass was proved by these experiments, a variation of less than 0·4 inch in the Boty lamp being sufficient to produce or prevent explosion outside. The trials also show that the Davy of small diameter, still used in England by the fire-trier, but abandoned in the Anzin and Bessèges collieries, presents important advantages, and if sufficiently protected against strong currents would possess a high degree of safety. They further demonstrate that the electric spark is essentially dangerous in fiery mines: which should be borne in mind in any attempts to introduce electric lighting in colliery workings.

Investigating experimentally the mesh and shape of the wire-gauze cylinder, the Author concludes that, for the same total area of apertures per square inch, gauze of finer mesh is safer than a coarser and heavier make. The lamp inside should be as nearly cylindrical as possible throughout its entire height; and in particular the bottom of the gauze should be flush with the inner circumference of the glass. Any narrowing at this part, by the insertion of a horizontal annular diaphragm projecting inwards, or by contracting the gauze cylinder to a smaller diameter than the glass, is objectionable: doubtless because the explosive mixture inside the lamp gets thereby so churned up as to augment enor-

mously the rapidity with which it explodes, enabling the flame consequently to pass out through the gauze.

The comparative lighting power of the various lamps tried by the Author was found to be as follows:—

ENGLISH[1] STANDARD CANDLE, 100.

1. Westphalian	77	8. Mueseler, Belgian	49
2. Boty	72	9. „ English	44
3. Westphalian	70	10. Bainbridge	39
4. Marsaut	69	11. Davy, Dubrulle	32
5. Williamson	56	12. „ Gard	22
6. Thomas	53	13. „ Newcastle	20
7. Clanny	52	14. Stephenson	17

In the Westphalian lamps, Nos. 1 and 3, the air-inlet is through a collar of perforated sheet-iron all round the neck, below the bottom of the glass; No. 3 was protected by the addition of a layer of wire-gauze inside the perforated collar, but No. 1 was without this protection.

The lighting power seems to depend partly upon the metal of which the lamps are made, a brass lamp being found to give only 70 per cent. of the light obtained from the same make in wrought iron. The difference is no doubt connected with heat-conducting capacity. English lamps are generally made of brass, and German of wought iron. Mr. Marsaut is inclined to think steel, or perhaps malleable cast iron, would be advantageous.

[1] The *bougie de l'Étoile*, frequently taken in France for the standard of lighting power, and so adopted by the Author, is a stearine candle, of five to the pound, burning 9·6 grams per hour. The English standard is a sperm candle, of six to the pound, burning 120 grains per hour; it is found to give only 90 per cent. of the light from the French *bougie de l'Étoile*. Hence the Author's own percentages in this comparison are 0·9 of those here given, and range from 69 per cent. for No. 1 down to 15 per cent. for No. 14.

(*Paper No. 1923.*)

"The River Thames."

By John Baldry Redman, M. Inst. C.E.

The Tables accompanying this memorandum, in continuation of those appended to previous Papers by the Author,[1] show plainly the continued development of flux and reflux of the tide in the Port of London. Taking the lowest ebb ever registered at the Shadwell entrance of the London Docks, which was 23 feet 6 inches below Trinity standard, and the greatest elevation of 5 feet above that standard at Westminster, the result is a maximum vertical oscillation of 28 feet 6 inches. The range of the A.M. tide on the 28th of October, 1882, at Sheerness, was 17 feet, and at Shadwell 23 feet 2 inches; the high waters were relatively 6 inches below and 4 feet 6 inches above Trinity, and the super-elevation of the tidal surface was therefore 5 feet, and the low waters were relatively 17 feet 6 inches and 18 feet 8 inches below Trinity, with a low water in London 14 inches lower than at sea. It must, however, be noted that the low waters for the average of the ebbs of the year are practically the same or level. At the height of spring-tides they are only a few inches lower in London, but during neap-tides they sometimes average 1 foot lower, from the fact that the tidal wave at the commencement of the flood is weaker than during spring-tides, and exerts less influence in checking the momentum of the ebbing water. With westerly gales this excess of depression mounts up to from 2 feet to more than 4 feet. Taking the averages of the last ten years, the following are the mean differences for all the tides of the year: a low-water depression of 2½ inches in the Port of London as compared with Sheerness; during ordinary springs a depression of 1½ inch in favour of Sheerness, but during neaps, of 5¾ inches in favour of London. The statement in reference to low water in London being frequently lower than at sea has met

[1] Minutes of Proceedings Inst. C.E., vol. xlix., 1876-77, part iii., p. 67; vol. lix., 1879-80, part i., p. 286.

with so much incredulity, that the following test, readily made by any one interested, is suggested.

Trinity standard is 25 feet 4 inches on the London Dock Upper Shadwell sill. This can be proved by the nearest O.B.M. The zero of the tide-gauge of Sheerness Dockyard mean level of sea is 11 feet 3 inches below Trinity. This can be proved in the same way. Major-General Bayley, R.E., when at Southampton, however, valued the Sheerness zero at 11 feet 1 inch. The Admiralty half-spring tidal range for Sheerness is 8 feet, and for London 10 feet 4 inches. That would show that there was nothing extraordinary, bearing in mind the above facts, in a super-elevation in London of 5 feet at high-water, and an excess of depression of 2 to 4 feet at low-water under certain conditions.

It must, however, be borne in mind that the average estimated mean tide-level is 1 foot 3 inches higher in London than at Sheerness. There was therefore, with the relative ranges of 16 feet and 20 feet 8 inches of average spring-tides, a super-elevation of 3 feet 7 inches at high-water in the Port of London, and a low-water depression of 1 foot 1 inch as compared with that at sea.

As regards excess of range due to gales of wind, over the computed heights above Trinity, which do not take that element into account, the following general results are given :—

	Computed.		Observed.		
	Ft.	Ins.	Ft.	Ins.	Date.
From 1860 to 1863	0	6	3	6	in Dec. 1863.
„ 1864 „ 1866	0	6	3	6	„ Nov. 1866.
„ 1867 „ 1868	0	4	3	0	„ Feb. 1868.

After this, owing to the altered conditions of the river, brought about by the causes before described, the following excesses were observed.

		Computed.		Observed.		
		Ft.	Ins.	Ft.	Ins.	
1869	March	..		3	7	London Docks.
	October	1	8	..		„
1870	February	..		3	0	„
	March	2	0	..		„
1871	April	1	8	..		„
1872	April	..		2	10	„
	September	1	7	..		„
1873	February	..		3	3	„
	October	2	0	..		„
1874	March	2	1	4	4	Westminster.
1875	April	1	10	..		„
	November	..		4	9	„

		Computed. Ft. Ins.	Observed. Ft. Ins.	
1876	September	1 5	..	Westminster.
	June and December	..	1 11	"
1877	January	..	4 4	"
	March and September	1 11	..	"
1878	March	2 1	..	"
	November	..	3 1	"
1879	March	1 10	..	"
	April	..	3 6	"
1880	March	1 6	..	"
	November	..	2 9	"
1881	January	..	5 0	"
	September	1 11	..	"
1882	February	..	4 6	"
	August and September	2 1	..	"
	October	..	5 0	"

NOTE.—From 1869 to 1873 the observed heights are for the London Docks; from 1874 to 1882 at Westminster, so that the excess is somewhat exaggerated, as the Admiralty computed heights are for London Bridge, where the reading will be quite 2 inches lower. In effect, N.N.W. gales, during the equinoxes and heavy floods, raise the tidal column 1 yard above the computed heights in the Port of London, the surface of the water rising upwards tolerably uniformly at 1¼ inch per mile in the 48 miles from Sheerness to London, but during E.N.E. gales, for the last seven years, this super-elevation of 5 feet has at times increased to from 6 feet to 7 feet.

[APPENDIX.

APPENDIX.

TABLE 5.—RIVER THAMES. MAXIMUM CALCULATED ADMIRALTY SPRING RANGES—*continued from vol. xlix., p.* 103.

	1878		1879		1880		1881		1882		1883	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Sheerness	17	6	17	4	16	11	17	4	17	5	17	6
London	22	3	22	0	21	8	22	1	22	3	22	3
Differences . . .	4	9	4	8	4	9	4	9	4	10	4	9
Low water on Wapping sill . . .	2	9	2	9	2	9	2	9	2	9	2	9
Admiralty London half range . . .	10	4	10	4	10	4	10	4	10	4	10	4

TABLE 7.—RIVER THAMES. HIGH WATER and LOW WATER COMPARISONS BELOW TRINITY STANDARD, as observed—*continued from vol. xlix., p. 110.*

N.B.—The high-water levels marked thus * are *above* Trinity standard; and the low-water differences marked thus * are *lowest* in the Port of London. The mark † denotes strong wind.

—	London.			Sheerness.			Difference at H. W.	Difference at L. W.	Difference of Range.	Wind.
	H. W.	L. W.	Range.	H. W.	L. W.	Range.				
	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	
1876										
Feb. 13 A.M.	1 1*	21 4	22 5	2 10	20 2	17 4	3 11	1 2*	5 1	E.
Dec. 2 P.M.	1 11*	19 4	21 3	3 10	19 1	15 3	5 9	0 3*	6 0	S.W.
1877										
Jan. 2 A.M.	4 0*	17 10	21 10	0 6	18 6	18 0	4 6	0 8	3 10	N.
Mar. 2 A.M.	0 9*	20 8	21 5	3 7	22 9	19 2	4 4	2 1	2 3	W.S.W.
Apr. 17 A.M.	2 1*	..	..	4 10	..	..	6 11	..	..	E.N.E.†
1878										
Jan. 21 A.M.	0 11	23 2	22 3	4 10	22 7	17 9	3 11	0 7*	4 6	S.W.†
P.M.	0 9*	..	..	2 11	18 7	15 8	3 8	..	..	
Nov. 28 P.M.	3 1*	..	..	1 7	16 8	15 1	4 8	..	..	N.N.E.
1879										
Oct. 18 A.M.	3 2*	..	..	0 10	..	..	4 0	..	..	N.W.
1880										
Jan. 14 P.M.	1 6*	20 4	21 10	2 11	20 10	17 11	4 5	0 6	3 11	
Apr. 26 P.M.	1 11*	20 0	21 11	2 11	20 3	17 4	4 10	0 3	4 7	
1881										
Jan. 18 P.M.	4 8*	17 4	22 0	1 9	17 8	15 11	6 5	0 4	6 1	Snow, E.N.E.†
Feb. 7 P.M.	6 3	18 0	11 9	9 6	17 7	8 1	3 3	0 5*	3 8	S.
„ 8 A.M.	6 2	16 10	10 8	8 6	15 11	7 5	2 4	0 11*	3 3	W.†
„ 9 P.M.	3 3	16 0	12 9	6 9	14 6	7 9	3 6	1 6*	5 0	W.N.W.
„ 10 A.M.	4 11	16 10	11 11	8 2	18 0	9 10	3 3	1 2	2 1	
Oct. 14 P.M.	9 6	23 6	14 0	11 9	17 5	5 8	2 3	6 1*	8 4	W.S.W.† Gale.
„ 15 P.M.	3 9	16 1	12 4	7 0	11 3	4 3	3 3	4 10*	8 1	W.†
1882										
Feb. 19 P.M.	4 4*	17 10	22 2	0 5*	18 11	19 4	3 11	1 1	2 10	W.N.W.†
Mar. 22 P.M.	2 10*	21 4	24 2	0 6	21 6	21 0	3 4	0 2	3 2	N.N.W.†
Oct. 28 A.M.	4 6*	18 8	23 2	0 6	17 6	17 0	5 0	1 2*	6 2	
to P.M.	4 4*	..	..	0 1	17 11	17 10	4 5	..	..	

TABLE 9.—RIVER THAMES—*continued from vol. xlix., p.* 113.

	1877.				1878.				1879.			
	Below Trinity Standard L. W.	Below Trinity Standard H. W.	Range.	Below Trinity Standard Half Tide.	Below Trinity Standard L. W.	Below Trinity Standard H. W.	Range.	Below Trinity Standard Half Tide.	Below Trinity Standard L. W.	Below Trinity Standard H. W.	Range.	Below Trinity Standard Half Tide.
	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
Average of Year—												
Sheerness . . .	18 8½	4 9⅞	13 10⅜	11 8⅞	18 6⅞	4 9¼	13 9⅝	11 8	18 9¼	4 10⅝	13 10⅝	11 9⅞
London	18 8¾	0 9⅛	17 11⅝	9 8⅞	18 10⅝	0 10⅛	18 0½	9 10⅜	18 8⅜	0 9¼	17 11⅛	9 8¾
Differences . . .	0 0½*	4 0¾	4 1¼	2 0	0 3¾*	3 11⅛	4 2⅞	1 9⅝	0 0⅞	4 1⅜	4 0½	2 1⅛
Springs—												
Sheerness . . .	19 7⅞	3 4⅝	16 3¼	11 6¼	19 7⅞	3 5⅛	16 2¼	11 6¾	20 5⅛	2 10⅛	17 6⅞	11 8
London	19 8⅛	1 0½*	20 8⅝	9 3¾	19 11⅛	0 9⅞*	20 9	9 6⅝	19 8¼	1 5½*	21 1¾	9 1⅝
Differences . . .	0 0¼*	4 5⅛	4 5⅜	2 2½	0 3¼*	4 3½	4 6¾	2 0⅛	0 9¼	4 4⅛	3 6⅞	2 6⅜
Neaps—												
Sheerness . . .	16 8⅞	7 2¾	9 6	11 11⅝	16 10⅛	7 1⅞	9 9¼	12 0⅜	17 1⅜	7 3½	9 9⅞	12 2⅜
London	17 8⅝	4 0⅝	13 8	10 10⅝	17 10½	3 11¾	13 10¾	10 11⅛	17 2⅞	3 6	13 8⅞	10 4⅜
Differences . . .	0 11¾*	3 2⅛	4 2	1 1	1 0⅜*	3 2⅛	4 1½	1 1¼	0 1½*	3 9½	3 11	1 10

NOTE.—The high-water levels marked * are *above* Trinity standard. The low-water differences marked * are *lowest* in London.

TABLE 9.—RIVER THAMES—*continued.*

	1880.								1881.								1882.							
	Below Trinity Standard L. W.		Below Trinity Standard H. W.		Range.		Below Trinity Standard Half Tide.		Below Trinity Standard L. W.		Below Trinity Standard H. W.		Range.		Below Trinity Standard Half Tide.		Below Trinity Standard L. W.		Below Trinity Standard H. W.		Range.		Below Trinity Standard Half Tide.	
Average of Year—	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Sheerness . . .	18	8	4	11⅜	13	8⅝	11	9⅝	18	10½	4	9½	14	1	11	10	18	10⅝	4	6⅞	14	3¾	11	8¾
London	18	8⅞	0	11¼	17	9⅝	9	10	18	11½	0	8⅞	18	2⅝	9	10⅛	19	1½	0	7½	18	6	9	10½
Differences . . .	0	0⅞*	4	0⅛	4	1	1	11⅝	0	1*	4	0⅝	4	1⅝	1	11⅞	0	2⅞*	3	11⅜	4	2¼	1	10¼
Springs—																								
Sheerness . . .	20	2⅛	3	4¼	16	9⅞	11	9⅛	20	2⅛	3	0⅜	17	1¾	11	7¼	19	9	3	1¾	16	7¼	11	5¾
London	19	5⅛	1	0¾*	20	5⅞	9	2⅛	19	7⅜	1	3⅜*	20	10¾	9	2	19	10¼	1	1*	20	11¼	9	4⅝
Differences . . .	0	9	4	5	3	8	2	7	0	6¾	4	3¾	3	9	2	5¼	0	1¼*	4	2¾	4	4	2	1⅛
Neaps—																								
Sheerness . . .	16	11⅛	6	11¼	9	11⅞	11	11⅛	17	2¾	6	9⅜	10	5⅜	12	0	17	5⅝	6	0	11	5⅝	11	8¾
London	17	1¼	3	4¾	13	8½	10	3	17	10¾	3	2¾	14	8	10	6¾	18	5¼	2	4½	16	0¾	10	4⅞
Differences . . .	0	2⅛*	3	6½	3	8⅝	1	8⅛	0	8*	3	6⅝	4	2⅝	1	5¼	0	11⅝*	3	7½	4	7⅛	1	3⅞

NOTE.—The high-water levels marked * are *above* Trinity standard. The low-water differences marked * are *lowest* in London.

TABLE 10.—RIVER THAMES. HIGH TIDES ABOVE TRINITY STANDARD at the LONDON DOCKS and WESTMINSTER.

	London Docks. Ft.	London Docks. Ins.	Westminster. Ft.	Westminster. Ins.	
2nd January, 1877	4	0	4	4	N., S.W.† on 1st
31st January, 1877	3	7	3	3	W.
8th October, 1877	3	7	3	6	N.N.W.†
11th February, 1879	2	11	3	6	S.W.
10th April, 1879	3	6	..		E.N.E.
19th November, 1880	2	9	..		
18th January, 1881	4	8	5	0	E.N.E.†
19th February, 1882	4	4	4	6	N.N.W.†
A.M. 28th October, 1882	4	6	..		
P.M. „ „	4	4	5	0	N.N.E.†

† Gales.

THAMES TIDES. ABSTRACT OF EXTREME EBBS EXCEEDING 20 FEET BELOW TRINITY STANDARD—*continued from vol. lix., p. 288.*

Sheerness.						London Docks.						
Year.	Total Number of Ebbs exceeding 20 Feet below Trinity Standard, and Dates of Lowest.	Below Trinity Standard + 20 Feet.		Trinity Standard 11 ft. 3 ins. above zero. Below zero of Tide Gauge + 8 ft. 9 ins.		Year.	Total Number of Ebbs + 20 Feet below Trinity Standard, and Dates of Lowest.	Trinity Standard on Tide Gauge 25 ft. 4 ins. Below Trinity Standard.		Above zero of Tide Gauge.	
		Ft.	Ins.	Ft.	Ins.			Ft.	Ins.	Ft.	Ins.
1879	Jan. 13th, A.M.	22	3	11	0	1879	Mar. 12th, P.M.	21	5	3	11
1880	Mar. 12th, A.M.	22	0	10	9	1880	Mar. 13th, A.M.	21	7	3	9
1881	Oct. 14th, P.M. Nov. 26th, P.M.	22 22	6 0	11 10	3 9	1881	Oct. 14th, P.M. Nov. 27th, P.M.	23 20	6 4	1 5	10 0
1882	Feb. 20th, A.M. April 18th, A.M.	22 21	5 10	11 10	2 7	1882	Feb. 20th, A.M. April 20th, A.M.	21 21	10 11	3 3	6 5
						1883	Jan. 25th, A.M. „ 26th, A.M.	22 22	6 0	2 3	10 4

(*Paper No. 1935.*)

"Note on Mr. G. H. Darwin's Paper 'On the Horizontal Thrust of a Mass of Sand.'"[1]

By PROFESSOR J. BOUSSINESQ, of the Faculty of Sciences, Lille.

(Translated by F. G. DELANO.)

MR. DARWIN's careful and extremely interesting experiments constitute a valuable control over the theory of the thrust of earth. They appear to confirm, to a much greater degree than their learned Author had imagined, the present writer's formulas, given in Section IX. of his memoir of 1876.[2] For the particular case of a horizontal mass retained by a vertical wall, these equations have been reproduced and developed by the Author, first in a contribution to the discussion on Mr. B. Baker's Paper,[3] and subsequently in a still more enlarged form, in the "Annales des Ponts et Chaussées."[4]

I. In the application of these formulas it is only necessary to note that the angle of friction, as determined by observing the greatest slope the sand takes when let fall carefully and without allowing of compression, is only that of the uppermost layers. Furthermore, the sand should only be poured from a height infinitely little; for as soon as the surface-slope approaches its limiting value, the smallest impact imparted by the succeeding layers suffices to propel the particles of sand to the base of the talus, and in this way to prevent their standing at the maximum slope. The coefficient of friction of the uppermost layers would probably be more exactly obtained by filling a large rough-bottomed box with sand, levelling off the top, and then gradually tilting the box until slipping began.[5] Then the angle above the horizon formed

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[1] Minutes of Proceedings Inst. C.E., vol. lxxi., p. 350.

[2] "Essai théorique sur l'équilibre des massifs pulvérulents," etc. Paris, Gauthier-Villars. Minutes of Proceedings Inst. C.E., vol. li., p. 277.

[3] Minutes of Proceedings Inst. C.E., vol. lxv., p. 212.

[4] "Annales des Ponts et Chaussées," June 1882, p. 625.

[5] Mr. Darwin states that in some few of his determinations of ϕ he used this method.—SEC. INST. C.E.

by this surface would be the required angle of friction, and it would sensibly exceed, perhaps by 1° or 2°, that of a talus formed by pouring, even most carefully, the sand against the wall destined to sustain it. It would also be thus found under conditions most nearly approaching those of practice. These latter also represent the conversion of a state of reposo into one of motion, while the act of pouring sand on a slope, to be there arrested, represents the passage from a state of motion to one of repose. It is always desirable to determine physical constants by means of experiments as closely as possible analogous to the conditions of actual practice.[1] But if already the coefficient of friction of the upper layers rather exceeds the angle they make when falling, that of the interior layers will show a much greater excess. Actually, the interior layers are sensibly compressed, although much less than would result from shaking the mass and smoothing it with a piece of wood. And this partial compression will inevitably have a twofold effect; on the one hand, to render the average density (that given by a weighing of the whole mass, 1·40 for Mr. Darwin's sand) slightly greater than that of the superficial strata; and, on the other hand, to endow the whole mass with an angle of friction ϕ, rather greater than that of those layers, and so much the more greater than the angle assumed by the utmost inclination of an earthwork actually in process of formation.

The angle in question being 35° in the sand used by Mr. Darwin, it follows that the interior angle of friction will be comprised between 35° and the notably greater value which it attained in Series II., where, the sand being compressed as much as possible, attained a density of 1·55. By inclining the box until a disturbance of the surface was produced, Mr. Darwin would probably have been able to observe directly this maximum value of ϕ. In default of a direct evaluation, it can only be deduced from a comparison of the theoretical formula for the moment of thrust with its experimental value, given in Series II. The superior limit of ϕ once found in this way, it would be natural to adopt, as a value of ϕ for a mass of sand imperfectly compressed by its own weight alone, the arithmetic mean between this superior limit and the known inferior limit, 35°. Viewed in

[1] May it not be possible that between two layers of sand, for instance, as between certain solids sliding one on the other, the friction at a uniform normal pressure will at first be a little greater than after motion has begun? Now that would suffice to render the angle of friction ϕ, in a mass passing from stable equilibrium to a state of motion, greater by several degrees than in the converse case.—J. B.

this light, the theoretical results agree remarkably with those of observation.

II. The Author will first refer to the series of experiments (I.–IV.) where the thrust on a yielding wall was produced by the height h of a mass of sand with a plane upper surface. From the results of his approximate integration of the equations, he has found that the moment of thrust about the base of the wall $=$ $\frac{1}{6}\,\Pi\, h^3\, K \cos\phi$, where Π is the specific gravity of the sand, and $K\cos\phi$ a coefficient, for which an inferior limit is obtained by putting

$$K \cos \phi = \tan^2 \left(\tfrac{1}{4}\pi - \tfrac{1}{2}\phi\right) \frac{\cos\left(\frac{1}{4}\pi - \frac{1}{2}\phi\right) \cos\phi}{\cos\left(\frac{3}{2}\phi - \frac{1}{4}\pi\right)} \quad . \quad . \quad (1)$$

and another, in excess, by using the same formula, but considering ϕ as no longer the angle of friction, but the angle, slightly less, given by the equation

$$\sin\phi = \frac{\sin\phi' + \sqrt{8 + \sin^2\phi'}}{4} \sin\phi' \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where ϕ' is itself the given angle of friction. In this way the mean of these two values may be regarded as the theoretical expression of $K\cos\phi$.

In the first place, let there be determined by the preceding formulas the value of ϕ for sand thoroughly compressed, by taking the result expressive of the experiments in Series II., which is equivalent to putting $K\cos\phi = 0{\cdot}132$. After a few trials this value of ϕ is found to be 46°; for the expression (1) $K\cos\phi$ has then the value 0·1151, and that deduced from (2) and (1) by making $\phi' = 46°$ (whence $\phi = 40°\ 52'$) is 0·1497. The arithmetic mean of these two results, or what may be regarded as the theoretical value of $K\cos\phi$, is equal to 0·1324, a coefficient nearly identical with that derived from observation. If ϕ had been taken as 45°, the formula (1) would have given $K\cos\phi = 0{\cdot}1213$, and the relations (2) and (1), in which ϕ' is taken as 45° (whence $\phi = 39°\ 49'$) would have given for the other limit 0·1577; the mean 0·14 would have been a little too high.

The angle of friction for sand thoroughly compressed being about 46°, the value of ϕ most suitable for the observations other than those of Series II. will be (as has been said) the mean of 35° and 46°, or 40½°. The excess of this number over 35° is not at all out of the way if it be remembered that, according to the explanation given above, the true angle of friction for the super-

ficial layers was probably not 35° but rather 36° or 37°. It is nevertheless possible that the proximity of the three sides and of the bottom of the box (of which Mr. Darwin only attempted to determine the influence in respect of the right and left sides) may, by slightly hindering the deformation of the sand, have produced up to a certain point the same effect as a slight increase of the angle of friction of the whole, so that the pulverulent mass thus restrained by the fixed sides would comport itself in respect of the single movable one, considered in the formulas, as a mass of uniform density beyond the influence of these side walls, but having an interior angle of friction ϕ a little larger than that of the sand used in the experiments. If this be so, the value $\phi = 40\frac{1}{2}°$ just obtained by comparing the formulas with the actual results of Series II., would probably exceed the mean angle of friction of the interior strata by an amount, doubtless very small, which it is well to retain in order to take some account of that part of the influence of the fixed sides neglected by Mr. Darwin.[1]

If, then, the calculation be made from (1) under these conditions, viz., with $\phi = 40\frac{1}{2}°$, the value of $K \cos \phi$ will be 0·1525; and if that from (2) and (1) be made on the assumption that $\phi' = 40\frac{1}{2}°$ (whence $\phi = 35° \; 13^1$), then $K \cos \phi = 0·1966$. The arithmetic mean of these two values is $K \cos \phi = 0·175$. It will be noticed that this number is very near those given by the experimental results of Series I., III., and IV., which are respectively 0·180, 0·165, and 0·189, and it is nearly identical with their mean, 0·178. It will also be seen that the superior and inferior limits, determined by the relations (1) and (2), appear to be nearly equidistant from the true result.

The differences existing between the three results 0·180, 0·165, and 0·189 is easily explained; for in Series III., where the layers of sand nearest the door of the box were poured in first, and had to support the others, their compression would be more complete than in Series IV., where they were poured in last. Also in Series III. the angle of friction was larger, and consequently the coefficient $K \cos \phi$ smaller. As regards Series I.,

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[1] It will be noticed that the ratio (0·88) of the angles of friction $40\frac{1}{2}°$ and 46° thus allowed, for sand imperfectly compressed by its weight alone and for sand thoroughly compressed by preliminary forcible pressure, is nearly the same as the ratio (0·903) of the two corresponding densities 1·40 and 1·55. And the ratio of the two sines $40\frac{1}{2}°$ and 46° approaches it still nearer (for it equals 0·9028 . . .). Will, then, the angle of friction of the same sand more or less compressed have its sine proportional to the density? This seems likely enough.—J. B.

where the sand was deposited in horizontal layers, it would naturally take a mean.

III. The Author now passes to the consideration of Series VI., where the upper surface having an angle above the horizon ω equal to 35°, the preceding formulas taken from the Author's remarks on Mr. Baker's Paper are no longer applicable. Here recourse must be had to those more general ones given in Section IX. (p. 126) of the Author's "Essai Théorique," before cited, which give

$$K \cos \phi = \tan \left(\tfrac{1}{4}\pi - \tfrac{1}{2}\phi\right) \frac{\cos \psi \cos (\phi + \delta) \cos \omega \cos \phi}{\cos (\phi - \delta) \cos (\omega + \psi)} \quad . \quad (3)$$

where the auxiliary angles ψ and δ are calculated by the equations (pp. 109 and 118)

$$\sin (\omega + 2\psi) = \frac{\sin \omega}{\sin \phi}, \quad \delta = \frac{\pi}{4} - \frac{\phi}{2} - \psi \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

It must be remembered that these formulas, as in the case of (1), only give an inferior limit of K cos ϕ. But a superior limit, which is above the true value by about as much as the inferior limit is below it, can be obtained by giving to ϕ a value a little less than the angle of friction, and such as to satisfy the equation

$$\frac{\sin \phi}{\cos \delta} = \sin \phi' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where ϕ' gives exactly the interior angle of friction, that is to say, $40\frac{1}{2}°$. This equation (4), of which the signification will be found at pp. 116 and 125 of the "Essai Théorique," includes, as a particular case, the preceding (2), to which it is equivalent when $\omega = 0$; and its employment for obtaining a superior limit of K cos ϕ is justified in exactly the same manner as is (2) in the last part of the Author's remarks on Mr. Baker's Paper. It is to be remarked that this equation (4) has always an appropriate root, at least when the angle ω is positive; for, on the one hand, whether ω is positive or negative, the expressions (3a), which suppose $\phi > \sqrt{\omega^2}$ furnish a value of δ comprised between 0 and $\frac{1}{2}\pi$ as will easily be seen; on the other hand, when ω is positive, this value of δ disappears for $\phi = \omega$, in such a way that if, in equation (4), ϕ is increased from ω to $\frac{1}{2}\pi$, ϕ', at first equal and then greater than ϕ, takes successively all the values comprised between ω and $\frac{1}{2}\pi$. There exists, therefore, at least when ω is positive, a root ϕ, whatever may be the value of ϕ'.

Thus, let there be taken from (3a) and (3), $\omega = 35°$, $\phi = 40\frac{1}{2}°$.

There results $\psi = 13° 31'$, $\delta = 11° 14'$, and the inferior limit of $K \cos \phi$ is found to be $0 \cdot 2992$. Let the superior limit now be sought by trying to satisfy (3a), (4) and (3) with $\phi' = 40\frac{1}{2}°$. After a few trials it will be found necessary to take $\phi = 39° 40'$; whence $\psi = 14° 29'$, $\delta = 10° 41'$, and $K \cos \phi = 0 \cdot 3221$. Lastly, the mean of $0 \cdot 2992$ and $0 \cdot 3221$, or the theoretical value sought, is $K \cos \phi = 0 \cdot 3107$. If, for the angle of friction, 40° had been taken instead of $40\frac{1}{2}°$, the calculation of the inferior limit would have given $\psi = 14° 5'$, $\delta = 10° 55'$, $K \cos \phi = 0 \cdot 3126$, while, for the superior limit, it would have been necessary to take $\phi = 39° 13\frac{1}{2}'$, $\psi = 15° 2\frac{1}{2}'$, $\delta = 10° 20\frac{1}{3}'$, and $K \cos \phi$ would have been found equal to $0 \cdot 3356$; whence the mean or theoretical value $K \cos \phi = 0 \cdot 3241$. It appears that it shows a considerable excess over the preceding value $0 \cdot 3107$, consequently a small variation in the angle of friction suffices here to alter sensibly the coefficient $K \cos \phi$. It would be enough to increase the value of the angle of friction, which has been adopted as a mean from $40\frac{1}{2}°$ to about $41\frac{1}{4}°$, in order to make this coefficient $K \cos \phi$ identical with that given by experiment, viz., $0 \cdot 291$. Now there would be nothing extraordinary in such an increase of three-quarters of a degree; for in Series VI. the sand next the partition, situated above the level of its lower extremity, was generally in larger masses than in the others, and it would consequently be rather more compressed than it generally was in the experiments of the preceding series.

But the slightly smaller value of $0 \cdot 291$ compared with $0 \cdot 3107$, may also be explained by observing that the superficial strata, slightly less dense than the rest, will, to some extent, behave as to the pressures they exert, as they would do if, by a slight diminution of their thickness, they were invested with the average density of the mass. Whence it follows that the effective height h of the sand against the wall would have to be reduced by a very small fraction of its value in order to assimilate the pulverulent mass more exactly to a homogeneous body. Therefore, in the expression $\frac{1}{6} \Pi h^3 K \cos \phi$ for the moment of thrust, the factor h^3 is taken a little too large when h is considered as the whole depth; which has the effect, the product being given, of lessening the other variable, *i.e.*, the empirical coefficient, which thus becomes a little less than $K \cos \phi$. But the correction necessary in h to compensate for this greater lightness of the superficial layers appears so slight as to elude evaluation, or, to put it otherwise, to defy the disengagement of its influence from that of the accidental variations affecting the angle of friction ϕ. It is therefore better neglected.

IV. There remains to examine Series V., where the surface of the sand took its natural slope, and made an angle with the horizon $\omega = - 35°$. Unfortunately for such large negative values of ω, the angle δ defined by the formula (3a), while still less than 90°, yet becomes considerable, for it varies from $\frac{1}{2}\pi - \sqrt{\omega^2}$ to 0, whilst ϕ increases from $\sqrt{\omega^2}$ to $\frac{1}{2}\pi$; and it is not merely by a few degrees but by a considerable amount that ϕ' in (4) exceeds ϕ. Thus the approximation given by the foregoing formulas depends on the difference between the angles ϕ' and ϕ, or is of the order $\frac{\sin \phi'}{\sin \phi} - 1 = \frac{1}{\cos \delta} - 1$, and the formulas become of no use when these two angles differ greatly from each other. The case under consideration can therefore only be precisely calculated when some means may be known of surmounting, otherwise than has been done here, the difficulties presented by the integration of the partial differential equations for the limiting equilibrium of loose earth.

Nevertheless the attempt may be made to arrive theoretically at some just idea of the proportions that will therein obtain of the coefficient $K \cos \phi$, by continuing to use equations (3) and (3a). Practically these are in no wise inapplicable to the purpose, and they always afford an inferior limit of $K \cos \phi$; they even supply a superior limit when there can be found for ϕ some value, less than the angle of friction, which satisfies the equation (4), in which ϕ' has been taken as exactly equal to this angle. But then such a root ϕ only exists, for a given negative value of ω, when ϕ' exceeds a certain minimum, notably greater than $\sqrt{\omega^2}$. It will be observed that, as ϕ increases from $\sqrt{\omega^2}$ to $\frac{1}{2}\pi$, $\cos \delta$ increases from $\sin \sqrt{\omega^2}$ to 1; and consequently in virtue of (4) ϕ' acquires the same value $\frac{1}{2}\pi$ for the first of these limits as for the second. It follows that this angle ϕ', besides being always comprised between ϕ and $\frac{1}{2}\pi$, never falls to $\sqrt{\omega^2}$. And its least value must of course increase with the absolute value of ω; because, when $\omega = 0$, formula (2) shows that ϕ' can be made to approach zero as nearly as may be desired. When ϕ' is given the value of ω cannot fall so low as $-\phi'$ if the root ϕ of equations (3a) and (4) is to continue to exist.

The negative limit of ω, or limit below which this root ϕ disappears, can be obtained approximately by seeking among a certain number of values of ϕ that one which gives to ω the greatest negative value. The value of δ (whence is deduced $\psi = \frac{1}{4}\pi - \frac{1}{2}\phi - \delta$) is always found directly by equation (4), and that of ω is deduced from the first (3a), which, after the substitu-

tion of $\sin \omega \cos 2\psi + \cos \omega \sin 2\psi$ for $\sin(\omega + 2\psi)$, gives as the solution

$$\tan \omega = \frac{\sin \phi \sin 2\psi}{1 - \sin \phi \cos 2\psi} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

In this way will be found the greatest negative value of the inclination $\tan \omega$ of the talus for which equations (3), (3*a*) and (4) allow simultaneously both an inferior and a superior limit of $K \cos \phi$. Beyond this it will only be possible to obtain an inferior limit; but it is justifiable to proceed further in the same direction, trusting to the principle of the continuity of phenomena in order to give the limits of a region within which must be the true values of $K \cos \phi$.

Taking then, in (4), $\phi' = 40\frac{1}{2}°$, let there be given to ϕ values such as 20°, 21°, 22°, &c., then formulas (4) and (5) will give—

for $\phi = 25°$, $\delta = 49° \, 24'$, $\psi = -16° \, 54'$, $\omega = -19° \, 55'$,
for $\phi = 25\frac{1}{2}°$, $\delta = 48° \, 29'$, $\psi = -16° \, 14'$, $\omega = -19° \, 57'$,
for $\phi = 26°$, $\delta = 47° \, 33'$, $\psi = -15° \, 33'$, $\omega = -19° \, 56'$.

The greatest possible negative value of ω is $\omega = -19° \, 57'$ corresponding to $\phi = 25\frac{1}{2}°$. If then these values and their corresponding ones, $\delta = 48° \, 29'$, $\psi = -16° \, 14'$ be used in formula (3), be taken, it will be seen that the superior limit (for $\omega = -19° \, 57'$) of $K \cos \phi$ is 0·1909. As regards the inferior limit, obtained by making (3*a*) and (3) $\omega = -19° \, 57'$ and $\phi = 40\frac{1}{2}°$ (whence $\psi = -5° \, 52\frac{1}{2}'$ and $\delta = 30° \, 37\frac{1}{2}'$), it is $K \cos \phi = 0·1196$. There results then, 0·1552 as thé arithmetic mean of the two limits. If this be regarded as the true value of $K \cos \phi$ it will be seen that the error of the inferior limit will be $0·1552 - 0·1996 = 0·036$ nearly. This error, being always of the order $\frac{1}{\cos \delta} - 1$, would naturally become greater still if the inclination ω of the surface with the horizon should exceed 19° 57′, which would lead to an increase of δ. It therefore follows that in cases where the negative values of ω exceed 19° 57′, and consequently where only the inferior limit of $K \cos \phi$ will be calculable, the difference between this limit and the true value of $K \cos \phi$ will be greater than 0·036.

Now, taking account of these indications, suppose that the value of $K \cos \phi$ is to be determined when $\omega = -35°$, as in Series V. of Mr. Darwin's observations. In (3*a*) and (3) let $\phi = 40\frac{1}{2}°$, $\omega = -35°$ (whence $\psi = -13° \, 31'$, and $\delta = 38° \, 16'$), there results $K \cos \phi = 0·082$. But this coefficient being presumably less than the truth by a quantity greater than 0·036, the

true value will exceed $0 \cdot 082 + 0 \cdot 036 = 0 \cdot 118$. On the other hand it seems evident *à priori* that the thrust is less when the talus $\tan \omega$ of the surface is negative than when it is nil, and greater in proportion as this talus is greater in absolute value, since in that case the wall has less sand close to it above its bottom to support. Therefore the true value of $K \cos \phi$ should be greater than $0 \cdot 118$ and less than $0 \cdot 155$, a value attributed to it when ω equalled $- 19° 57'$. The result of all these considerations would therefore be to give $K \cos \phi$ a value of about $0 \cdot 14$, while actual experiment places it at $0 \cdot 147$.

Thus theoretical indications, although vague enough in the case actually considered, where ω has high negative values, may still render some service, at any rate in directing the mind to the order of magnitude of the results. Further, it is well to note that this, the least favourable of all cases for the employment of equations, has little practical importance.

V. In conclusion, Mr. G. H. Darwin's valuable observations appear to confirm as fully as possible the Author's formulas for the thrust of a pulverulent mass in limiting equilibrium. These formulas are due to Rankine's principles, simply developed and completed by the addition of the element of slip of the mass against the wall sustaining it, and constituting in this form the rational and corrected expression of principles due to Coulomb himself. Coulomb's theory, in all cases where it is justifiable to apply his fundamental hypothesis of a plane rupture of the mass, gives identically the same results as Rankine's formulas, as has been shown by Mr. Maurice Levy.[1] It will then be found that these instances (of which the most important is where $\omega = \phi$, and consequently $\psi = \frac{1}{4} \pi - \frac{1}{2} \phi$ and $\delta = 0$) are just those in which the Author's formulas merge into those of Rankine, in such a way as to represent all that may now be retained of the old theory of Coulomb.

[N.B. The Author does not dispute that Mr. Darwin's tentative method, given in the second part of his memoir (p. 24), may afford a general idea or outline of what is passing at the moment when the revetment-wall begins to overturn. Virtually, at that time the wall, even while yielding, still gives a partial support to the mass, which allows that portion of the latter, which yet continues nearly immovable, to maintain with the horizon angles greater than the angle ϕ of its natural slope. Such angles being thus comprised between the limits ϕ and $\frac{1}{2} \pi$, it is not impossible that they may differ but slightly from the mean $\frac{1}{2} \phi + \frac{1}{4} \pi$; whence it follows that the other portion of the mass, namely, that which is

[1] Liouville's "Journal de mathématiques pures et appliquées," 1873.

beginning to descend, and which is comprised between the foregoing and the vertical wall, may well differ but little from a wedge of earth having its inferior edge contiguous to the base of the wall, and its two adjacent faces mutually inclined at the angle $\frac{1}{4}\pi - \frac{1}{2}\phi$, complementary to the preceding. Mr. Darwin's formula, which is a return to

$$K \cos\phi = \sin^2\left(\tfrac{1}{4}\pi - \tfrac{1}{2}\phi\right)\frac{\cos\omega\cos\phi}{\cos\left(\omega + \frac{1}{4}\pi - \frac{1}{2}\phi\right)\cos\left(\frac{2}{3}\phi - \frac{1}{4}\pi\right)},$$

is the expression of these hypotheses, in addition to another one, viz., that the point of thrust occurs at one-third the height of the wall. The Author would only observe that, even in the case of a horizontal mass retained by a vertical wall, reliance must not be placed on the opinion of Coulomb in considering the angle of the wedge of earth equal to $\frac{1}{4}\pi - \frac{1}{2}\phi$, for Coulomb was only led by his prism theory to attribute this value to it, because he supposed the wall to be infinitely smooth, or capable only of exercising normal reactions, which gave him for the horizontal component of the thrust exactly the value obtained by Rankine, and objected to by Mr Baker and Mr. Darwin as being much too large.—J.B.]

(*Paper No. 1934.*)

"Note on Mr. G. H. Darwin's Paper 'On the Horizontal Thrust of a Mass of Sand.'"

By Prof. JULES GAUDARD, of Lausanne.

(Translated by F. G. DELANO.)

MR. DARWIN has referred to a new and interesting consideration in what he terms the "historical element," that is to say, the mode in which the molecules of the earthy mass are grouped. His experiments lead him to conclude that the slipping of soils comports itself according to the older theory of Coulomb and of Poncelet, rather than to that of Rankine and Boussinesq; that is to say, that instead of a continuous deformation of the entire mass, local cracks occur which break off a series of prisms, each of which falls by itself almost intact. Calculations are given in support of this theory.

The Author's objections to the conclusions arrived at point specially to the explanations of the considerable discrepancies between the results of his observation and the formula of scientists. It would appear that Mr. Darwin's mode of experimenting is open to the following objections. Firstly, the box employed is perhaps too narrow, at least for the experiment with the sand at a slope (Series VI.). If the wall AD, Fig. 1, were pressed by an indefinite mass of sand, the line of rupture might be, for example, AFE; but by limiting the material by a wall BC too close to AD, it will happen that instead of the full prism of thrust AED, there will be only a partial prism AFCD, which will, of course, exert a lesser force against the wall AD. The second objection refers to the influence of the side walls, which the Author would be led to consider much greater than Mr. Darwin has done. If the objection to theory is its inapplicability to all but hypotheses of ideal simplicity, then also experiment has the disadvantage of difficulty in perfectly representing a simple case, and of indicating the elementary laws of a phenomenon. If Fig. 2 represents the horizontal section of Mr. Darwin's box, the Author does not admit that the movement of the contents is identical for

FIG. 1.

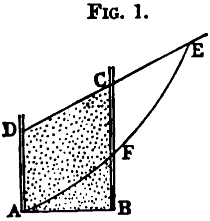
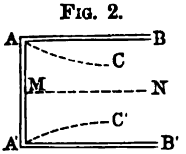


FIG. 2.



the different layers parallel to the sides AB, A′B′. He thinks, on the contrary, that the tendency to movement is considerably weakened near these partitions in virtue of their friction, insomuch that the maximum effect is on the axis MN. At the moment when the shutter AA′ begins to open, the first grains issuing probably do not escape from contact with the rough surfaces BA B′A′, but from some interior points CC′, the line of flow being oblique and curvilinear as in the case of a liquid, or even more accentuated. If this be so, the shutter AA′ will not encounter the full theoretical pressure, at the most such thrust will be felt at the centre M, that at the sides being much less. Representing the pressures at these different points by ordinates, there will result a representative curve such as $\alpha\, \beta\, \alpha'$, Fig. 3, of which the mean ordinate will be only a certain fraction of the maximum, or of the full theoretical pressure. Further, it is possible that this ratio of the mean ordinate to the maximum ordinate varies but little as the limits of length AA′ are reduced, and in this way, if an intermediate partition be inserted (Fig. 4),

Fig. 3.

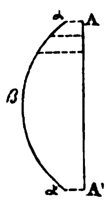


Fig. 4.

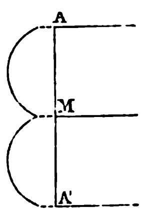
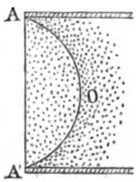


Fig. 5.



it may be that the total thrust is not greatly modified, supposing a very gradual flow of the sand.

If, instead of treating the phenomenon as an actual movement, it be considered in its static aspect, it may be necessary to consider the sand as buttressed against the side-walls, constituting itself a sort of vault AOA′, Fig. 5, in such a way that there is at first only a limited mass, AOA′ A, free to act against the wall AA′. The result will be the same: small pressures at A and A′, and maximum pressure at M. No doubt, from this point of view, the insertion of a partition at M would seem to necessitate the exertion of some influence greater than that shown by Mr. Darwin's experiments. The Author, however, does not pretend to elucidate this obscure point, but merely to suggest that experiments made with narrow boxes appear to indicate phenomena too complex to be of use for the correction of theory. In the case of an inclined mass, DC, Fig. 1, it appears natural that the discrepancy between theory

and experiment should be greater than in the case of a level, the frictional surface of the side walls being augmented.

The conclusion to be drawn from the anomalies indicated by Mr. Darwin seems to be that of two walls, one being continuous, while the other is furnished with a series of interior counterforts, dividing the upheld soil to a great depth, and at close intervals, the last-named would be subjected to a pressure much less than the first.[1] But in the present state of the question, one of these cases is known only by experience, while the other is known only by theory, circumstances which render any attempt at reconciling theory and practice very difficult.

The disposition of Mr. Darwin's apparatus, and notably the use of the spring-balance, is very ingenious. Colonel Audé ("Mémorial de l'Officier du Génie," vol. ix., 1847) devised a simple mode of dispensing with cords and pulleys. He attached to the movable shutter a post with a horizontal arm equilibrated by a counter-weight of sand, which was allowed to run off by degrees from an orifice at the bottom. At the moment of the fall of the shutter, it suffices to weigh the sand in order to deduce by a short calculation the value of the thrust. But Mr. Darwin's method is doubtless more convenient, inasmuch as it measures the effort produced at once, without necessitating any weighing.

The foregoing remarks are solely put forward in the hope that Mr. Darwin and other experimenters in this field may be induced to continue their observations; if possible greatly varying the dimensions of their apparatus, so that by affording more scope for comparison of the experiments, and the resulting discussions, more light may be thrown on this difficult question.

[1] This resistance of lateral friction of the earth is sometimes utilized for the consolidation of unstable slopes by constructing in the interior of the mass transverse walls perpendicular to the surface of the slope (Comoy, "Annales des Ponts et Chaussées," July 1875).—J. G.

(*Paper No. 1910.*)

"On the Behaviour of Steam in the Cylinders of Locomotives during Expansion."

By DANIEL KINNEAR CLARK, M. Inst. C.E.

THE influence of the mass of the cylinder on the behaviour and efficiency of steam was recognised as early as 1843, when Mr. Combes,[1] by a remarkable forecast, formed the opinion that in steam-engines a portion of the steam admitted into the cylinder was immediately condensed on the less hot metallic surfaces, which had, a second previously, been in communication with the condenser, and had had their temperature lowered in consequence; and that the condensation-water, independently of such water as might be drawn with the steam into the cylinder, was re-evaporated during the period of expansion, so that new quantities of steam were added to the steam already existing; and that the pressure fell less rapidly than in the inverse ratio of the volumes. This explanation appears to have been entirely overlooked.

Mr. Thomas Craddock,[2] in 1846, formed similar opinions, based on the fact of the constant presence of water in the cylinder, which he described as very probably occasioned by the cooling of the cylinder, in consequence of its communication with the condenser, and the condensation of part of the fresh steam admitted. He argued that the temperature of the vapour was reduced by the fall of pressure when the cylinder was opened to the condenser, below the temperature of the metal, and that consequently re-evaporation of condensation-water took place, and the cylinder was cooled down correspondingly.

Dr. Pole[3] similarly, in 1848, mentions the "accidental presence of water in the cylinder," whether in consequence of priming, or because "the temperature of the piston and the cylinder must be lower than that of the steam when first admitted, and a deposition of water will therefore take place at the commencement of the

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[1] Académie des Sciences. Comptes rendus, April 3rd (vol. xvi., p. 649) and November 20th (vol. xvii., p. 465), 1843.

[2] "The Chemistry of the Steam Engine," 1846.

[3] "A Treatise on the Cornish Pumping Engine," part iii., 1848, p. 190.

stroke." Moisture so introduced, he adds, would be re-evaporated as the steam expands.

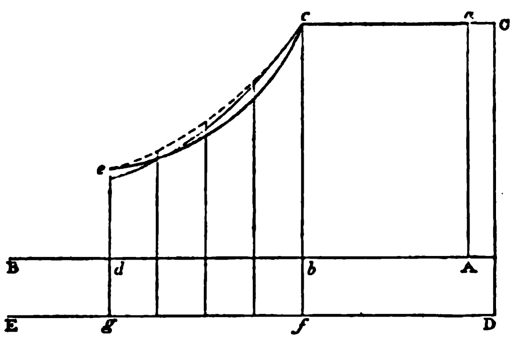
The Author,[1] unaware of what had previously been published, as matter of probability, was impressed, in the course of his investigations in 1851, on the behaviour of steam in locomotives, by the marked contrast between the expansion-curves of inside cylinders and those of outside cylinders, inasmuch as those of the former fell in pressure much more rapidly than those of the latter, and suggesting condensation in the course of the expansion, so that there appeared to be much more work done in the outside cylinder than in the inside cylinder, with steam of the same initial pressure. But, arguing that, in the inside and more or less heated cylinders, the steam must work more efficiently than in the outside and comparatively exposed cylinders, he conceived that the suggested action must be apparent rather than real, and that the comparative fulness of the diagram, and of pressure towards the end of the expansion-curve of outside cylinders, could only be derived from heat previously absorbed by the material of the cylinder from the steam when it was admitted, being in part re-appropriated in resuscitating condensed steam. Having obtained this clue to the condition and behaviour of steam in cylinders, the Author followed up the investigation experimentally, the results of which were published in 1851 and 1852, as already noted; and are here reproduced in abbreviated form, recalculated in accordance with the results of the more recent investigations of Mr. Regnault on the properties of steam.

The diagram, Fig. 1, shows the expansion-curve of an indicator diagram taken at low speed. Let A B be the atmospheric line, equal to the length of the stroke of the piston, and A *b* the period of admission of steam, and the height A *a* the uniform indicated pressure, 61 lbs., maintained during admission. Then the rectangle A *c* is the area of effective pressure, due to the period of admission under the steam-line *a c*. The thick-line expansion-curve *c e* shows the progressive fall of pressure to 23 lbs. during an increase of volume, when the face of the piston has passed from *b* to the release line *d e*. The total volume of clearance between the valve and the piston amounts to 1·1 inch in length of the cylinder, and this, added to the volume described by the piston, makes up the total volume of the steam. The stroke of the piston is 20 inches,

[1] "Expansive Working of Steam in Locomotives," Institution of Mechanical Engineers. Proceedings. 1852, pp. 63, 105. Also "Railway Machinery," 1851, pp. 77–85, and 1855.

and the points of cut-off and exhaust are, by measurement of the diagram, 6·9 inches and 15 inches from the beginning of the stroke. Add to each of these the clearance, 1·1 inch, and the sums, 8 and 16·1, are the inches of stroke occupied by the initial and the final volumes of steam, at the beginning and the end of the expansion. Add the rectangular space A C, 1·1 inch wide, to represent the clearance, and draw the zero line of pressure D E at a level 15 lbs., by scale, below the line A B, as the base-line for the expansion-curve. The total initial and final pressures of the steam during expansion, represented by *c f* and *e g*, are 76 lbs. and 38 lbs. Thus, while the total volume was increased from 8 inches to 16 inches, or doubled, the total pressure fell from 76 to 38 lbs.,

FIG. 1.



INDICATOR DIAGRAM FROM No. 33, C. R., TO ILLUSTRATE THE RATE OF EXPANSION.

or to one-half. Here is a coincidence with Boyle's law of expansion at the extremities of the curve; that is, the pressure is inversely as to the volume.

But if the period of expansion *f g* be divided into four equal parts, marked by vertical ordinates, these ordinates will measure successively 56 lbs., 47 lbs., and 41 lbs. of total pressure, for which the total volumes are 10 inches, 12 inches, and 14 inches of the stroke, respectively.

By Boyle's law these pressures would be:—

For 10 inches, $76 \times \frac{8}{10} = 60 \cdot 8$ lbs.
„ 12 „ $76 \times \frac{8}{12} = 50 \cdot 6$ „
„ 14 „ $76 \times \frac{8}{14} = 33 \cdot 4$ „

These are all in excess of the indicated pressures, and they belong to the curve *c e*, in dot lining, which properly represents

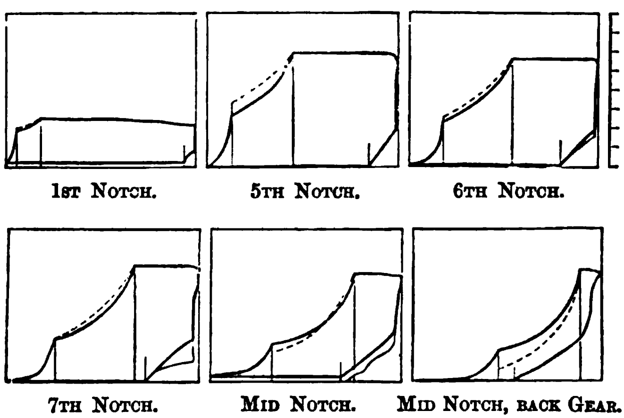
the result of Boyle's law, and which touches the actual curve only at the extreme points *c* and *e*.

Again, if the steam had neither parted with nor gained heat during the expansion, it would have expanded sensibly, according to the laws of simply saturated steam. The relative volume of saturated steam, of 76 lbs. absolute pressure, is 349, and this is doubled for the expanded volume, or becomes 698, which is the relative volume due to saturated steam of 36½ lbs., being 1½ lb. less than the indicated pressure.

For the three intermediate volumes the saturated pressures are found in the same way, 60 lbs., 49½ lbs., and 42 lbs. The four pressures thus found are exhibited by the curve of saturation represented by the lower curve in dot lining, Fig. 1, which, for the greater part of the expansion, lies above the curve actually described, and crosses and passes below it near the extremity. It is hence to be inferred that partial condensation of steam took place during the early part of the expansion, and was succeeded by a slight re-evaporation when the temperature of the steam, which fell with the pressure, became lower than that of the cylinder.

The expansion-curve now discussed belongs to one of a series of indicator diagrams, Figs. 2, taken consecutively from a cylinder

Figs. 2.



Slow Diagrams from No. 33, C. R.

of No. 33 passenger locomotive on the Caledonian Railway, with different periods of admission and expansion, as regulated by the notches of the valve-gear. The ratios of the initial to the final volumes expanded, clearance included, are from 1 to 1·14, to

1 to 3½, and the final pressures by Boyle's law vary from 2 lbs. in excess to 10 lbs. in deficit, compared with the indicated pressure. The curves of expansion due to Boyle are shown in dotting, and, taking them as approximately indicative of the lines of expansion, which would have been described had there not been any of the successive condensation and re-evaporation already referred to, it appears that, since the actual curve sinks below the dotted curve in the first stages of expansion, and rises above it in the later stages, if sufficiently prolonged, the steam was condensed and then re-evaporated, so that occasionally there is more sensible steam at the end than at the beginning. The mass of the cylinder is, in short, an equaliser tending to reduce inequalities of temperature and pressure.

These diagrams, Figs. 2, were taken after the engine had been at rest for some hours, when the cylinder had cooled considerably. The loss by condensation of steam admitted into comparatively cool cylinders is strikingly exemplified by the indicator diagram, Fig. 3, taken from No. 125, C. R., a goods engine with outside

FIG. 3.

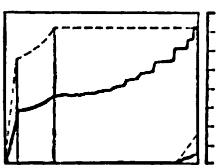
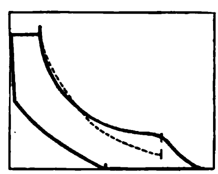
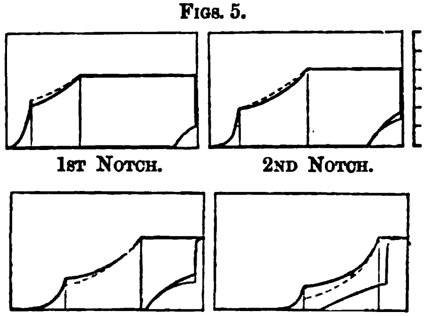


FIG. 4.



INDICATOR DIAGRAMS FROM No. 125, C. R., TO SHOW CONDENSATION OF STEAM.

FIGS. 5.



1ST NOTCH. 2ND NOTCH.

3RD NOTCH. MID NOTCH.

SLOW INDICATOR DIAGRAMS FROM No. 13, C. R.

cylinders, immediately at starting, after two hours of inactivity. The diagram presents a falling pressure during admission, the result of condensation; whereas, had the cylinder been quite hot, the curve would have followed the dotted lining. Again, the diagram,

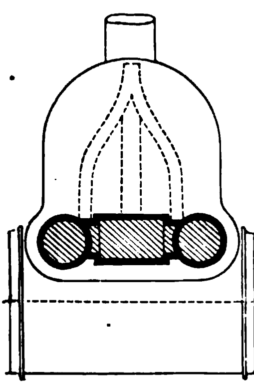
Fig. 4, from the same cylinder, cutting off at 3½ inches of the stroke, shows a large resuscitation of steam during the later part of the expansion.

The slow diagrams, Figs. 5, were taken from No. 13, C. R., immediately after having made an express trip, while yet the cylinders were hot. They are sharp and square, and exhibit nothing of the indecision noticeable in those taken from No. 33, Figs. 2. The dotted expansion lines show the curves according to Boyle's law, by which the pressures are inversely as the volumes; and in the hotter cylinder of No. 13 an expansion into one and a half time the initial volume brings up the pressure to an equality with that which is calculated by Boyle's law, as illustrated by the dot curves; though in No. 33, having the colder cylinder, an expansion into double the volume was required for the same result.

Of the Expansion of Steam in the Cylinder during regular Work.

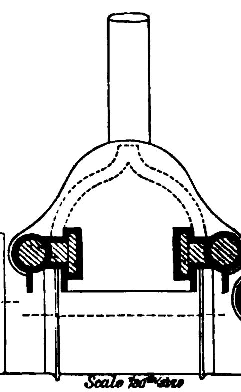
The following Table, No. I., contains dimensions and other particulars of some of the locomotives of the Edinburgh and Glasgow Railway, and the Caledonian Railway, with which experiments were made by the Author in 1850, on the expansive action of steam in the cylinder; also those of the "Great Britain"

Fig. 6.



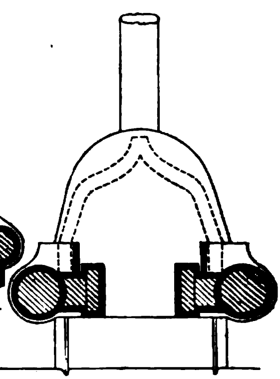
Great Britain, G. W. R.

Fig. 7.



Passenger, C. R.

Fig. 8.



Goods, C. R.

locomotive of the Great Western Railway, experimented with by Sir Daniel Gooch in the same year. All the engines were passenger locomotives except C. R. Nos. 125 and 127, which were goods locomotives. Cross-sections of the cylinders and smokeboxes are shown in Figs. 6, 7, and 8. The inside cylinders

were placed within the smoke-box and totally surrounded by the atmosphere of hot smoke; all the outside cylinders were those of locomotives on the Caledonian Railway. In general arrangement the Caledonian passenger-locomotives were much alike, the cylinders being fixed between outer and inner frame-plates, and embraced partially, at the upper part, by the plates of the smoke-box. At the outer and lower parts, the cylinders were practically beyond the reach of the heat that existed in the smoke-box, and there is no felting about them. The cylinders of the goods-engines, placed entirely clear of the smoke-box, were hung from the outside of the frame, not deriving any benefit from the warm atmosphere of the smoke-box, and protected from the weather only by a sheathing of felt and sheet-iron.

TABLE No. I.—DIMENSIONS of LOCOMOTIVES. 1850.

Designation of Locomotive.	Cylinder, Diameter and Stroke.	Driving-wheels, Diameter.	Position of Cylinders.
	Inches.	Ft. Ins.	
G. W. R. Great Britain	18 × 24	8 0	Inside.
E. & G. R. Nile	16 × 18	6 0	„
„ Orion	15 × 20	6 0	„
„ Hebe	15 × 20	5 6	„
C. R. No. 13	15 × 20	6 0	Outside.
„ No. 33	15 × 20	6 0	„
„ Nos. 41, 42	15 × 20	6 0	„
„ No. 51. old valve	15 × 20	6 0	„
„ No. 51, new valve	15 × 20	6 0	„
„ No. 125	17 × 24	4 7	„
„ No. 127	17 × 24	4 7	„

For the purpose of taking the series of indicator diagrams obtained, in 1850, by Sir Daniel Gooch, from the "Great Britain," the results of which are tabulated, special trains were prepared for the engine, and run over a 3-mile section, straight and level, of the Bristol and Exeter Railway.[1] They may be taken as standards of the performance of locomotives having well-protected cylinders. The indicator diagrams were taken for three periods of admission,

[1] These indicator diagrams are shown in diagram-plate iv. of "Railway Machinery."

cutting off at 16 inches, 11¾ inches, and 7 inches of the stroke respectively, and exhausting at 21⅝ inches, 19¼ inches, and 17⅜ inches. The exhaust-steam was shut in and compressed at 3 inches, 5 inches, and 7½ inches from the end of the return-stroke. The total clearance at each end, measured to the valve-face, was 1·80 inch, in parts of the stroke.

The Table No. II., founded on the indicator diagrams taken from the "Great Britain," exhibits the manner in which they have been analysed in relation to the expansion-lines. The points of cut-off and exhaust, including 1·80 lineal inch for clearance, with the initial and final volumes for expansion, are given in the subjoined tablet. The volumes are calculated as the product of the area of the piston, 1·767 square foot, by the periods of total admission, and the lineal measures of the total expanded volumes, in feet.

GREAT BRITAIN.	Cut-off plus Clearance.	Exhaust plus Clearance.	Initial Volume.	Final Volume.	Actual Ratios of Expansion.
Notch.	Inches or Feet.	Inches or Feet.	Cubic feet.	Cubic feet.	Ratio.
No. 1 . .	17·8 or 1·483	22·8[1] or 1·900	2·620	3·357	1 to 1·30
„ 3 . .	13·8[2] „ 1·150	20·8[2] „ 1·733	2·032	3·062	1 „ 1·50
„ 5 . .	8·8 „ 0·733	18·8[3] „ 1·567	1·295	2·769	1 „ 2·14

[1] The period of exhaust is taken at 21 inches, for a whole number, plus 1·8.
[2] The points of cut-off and exhaust are taken at 12 inches and 19 inches, plus 1·8 inch each.
[3] The point of exhaust is taken at 17 inches.

The observed speeds of the engine, and the calculated speeds of the piston, are stated in columns 2 and 3 of Table No. II. The sensible initial and final pressures of the steam, above the atmosphere, measured from the diagrams, are stated in columns 4 and 5. The initial and final weights of steam, assumed meantime to be saturated, columns 6 and 7, are calculated by multiplying the total volumes of the steams respectively, including clearance, by their densities or weights per cubic foot. Lastly, the differences of the initial and final weights of sensible steam, with their values as percentages of the initial weights of steam, are given in columns 8 and 9, the percentage in excess being marked + (plus), and those in deficiency marked − (minus).

It appears from the Table that, in nearly all instances, there is less sensible steam, taken as saturated, at the end of the expansion than at the beginning; also, that the influence of speed on the difference of the weight of steam is not appreciable except under the 1st and 5th notches, when at the two lowest speeds the final weight of steam is nearly the same as, or greater than, the

TABLE II.—"GREAT BRITAIN" LOCOMOTIVE—EXPANSION and WEIGHT of STEAM in the CYLINDER, from INDICATOR DIAGRAMS. 1850.

Cylinder 18 inches × 24 inches; total clearance 1·8 inches; wheel 8 feet. Steam assumed to be saturated, for calculation.

Number of Diagram.	Speed of		Net Pressure per Square Inch during Expansion.		Weight of Sensible Steam, as Saturated.			
	Engine.	Piston.	Initial.	Final.	Initial.	Final.	Difference.	
1	2	3	4	5	6	7	8	9
No.	Miles per hour.	Feet per minute.	lbs.	lbs.	lb.	lb.	lb.	Per cent.
FIRST NOTCH: Cut-off at 67 per cent.; exhaust at 89 per cent.; actual ratio of expansion, 1 to 1·30.								
25	15	210	70	50	0·5188	0·5163	0·0025	− 0·48
26	17	238	88	65	0·6218	0·6275	0·0057	+ 0·92
27	21	294	94	65	0·6549	0·6275	0·0274	− 4·18
28	24	336	84	57	0·5988	0·5681	0·0307	− 5·13
29	27	378	74	49	0·5416	0·5090	0·0326	− 6·02
30	31	434	86	55	0·6103	0·5533	0·0570	− 9·34
31	31	434	80	56	0·5760	0·5607	0·0153	− 2·66
32	49	686	52	34	0·4148	0·3958	0·0190	− 4·58
33	54	756	86	60	0·6103	0·5905	0·0198	− 3·24
Averages Nos. 27–33	34	474	79·4	53·7	0·5724	0·5436	0·0288	− 5·05
THIRD NOTCH: Cut-off at 50 per cent.; exhaust at 82 per cent.; actual ratio of expansion, 1·50.								
34	17	238	87	48	0·4777	0·4570	0·0207	− 4·33
35	18	252	70	37	0·4024	0·3953	0·0071	− 1·76
36	21	294	90	48	0·4905	0·4572	0·0333	− 6·79
37	26	364	72	38	0·4113	0·3886	0·0227	− 5·52
38	31	434	75	38	0·4245	0·3886	0·0359	− 8·46
39	32	448	79	38	0·4422	0·3886	0·0536	−11·58
40	40	560	65	33	0·3798	0·3540	0·0258	− 6·79
41	51	714	55	28	0·3349	0·3191	0·0158	− 4·72
42	55	770	72	37	0·4113	0·3816	0·0297	− 7·22
Averages Nos. 36–42	37	512	72·6	37·1	0·4133	0·3821	0·0312	− 7·55
FIFTH NOTCH: Cut-off at 29 per cent.; exhaust at 72·5 per cent.; actual ratio of expansion, 1 to 2·14.								
43	17	238	89	33	0·3099	0·3201	0·0102	+ 3·29
44	18	252	70	24	0·2565	0·2636	0·0071	+ 2·77
45	21	294	93	33	0·3208	0·3201	0·0007	− 0·22
46	28	392	74	21	0·2677	0·2439	0·0238	− 8·89
47	31	434	80	22	0·2847	0·2506	0·0341	−11·98
48	36	504	63	17	0·2365	0·2185	0·0180	− 7·61
49	50	700	55	15	0·2135	0·2057	0·0078	− 3·65
50	56	784	65	16	0·2421	0·2121	0·0300	−12·39
Averages Nos. 46–50	40	563	67·4	18·2	0·2489	0·2260	0·0229	− 9·20

initial weight. In these instances, it is intimated that preliminary condensation in a comparatively cool cylinder, and subsequent re-evaporation, took place. On the contrary, the reduction of weight of steam during expansion, when the cylinder is well warmed up, expressed in parts of the initial weight, increases as the ratio of expansion is increased, the average reduction amounting to 5·05 per cent., 7·55 per cent., and 9·20 per cent., for the 1st notch, 3rd notch, and 5th notch, respectively.

In the abstract Table, No. III., which follows, therefore, the speed

TABLE III.—EXPANSION and WEIGHT of STEAM in the CYLINDERS of LOCOMOTIVES, INSIDE and OUTSIDE, from INDICATOR DIAGRAMS. 1850.

INSIDE CYLINDERS.

Name of Engine.	No. of Notch.	Cut-off.	Ex-haust.	Actual Ratio of Ex-pansion.	Net Pressure per Square Inch during Expansion.		Weight of Sensible Steam, taken as Saturated.			
					Initial.	Final.	Initial.	Final.	Differences.	
1	2	3	4	5	6	7	8	9	10	11
	No.	P. C.	P. C.	Ratio.	lbs.	lbs.	lb	lb.	lb.	Per Cent.
Great Britain .	1	67·0	89·0	1·30	79·4	53·7	0·5724	0·5436	0·0288	− 5·05
" .	3	50·0	82·0	1·50	72·6	37·1	0·4133	0·3821	0·0312	− 7·55
" .	5	29·0	72·5	2·14	67·4	18·2	0·2489	0·2260	0·0229	− 9·20
Nile . .	Gab.	67·5	89·5	1·30	36·4	22·1	0·1921	0·1833	0·0088	− 4·57
Orion . .	5	56·7	89·0	1·50	46·5	21·5	0·1924	0·1806	0·0118	− 6·13
Hebe . .	5	44·4	77·0	1·64	46·0	19·0	0·1496	0·1417	0·0079	− 5·28
Averages .	..	52·4	..	1·56	..	..	..	..	..	− 6·27

OUTSIDE CYLINDERS.

C. R. No. 13	1	62·6	86·5	1·35	52·0	34·0	0·2269	0·2268	0·0001	− 0·04
"	2	49·0	81·5	1·60	45·0	24·0	0·1644	0·1735	0·0091	+ 5·54
C. R. No. 33	5	54·5	86·0	1·52	56·0	27·0	0·2049	0·1909	0·0140	− 6·83
"	7	34·5	75·0	2·01	46·0	16·5	0·1184	0·1281	0·0097	+ 8·19
C. R. No. 41	1	70·4	91·0	1·26	36·0	24·0	0·1940	0·1908	0·0032	− 1·65
"	2	64·0	86·0	1·31	26·0	16·0	0·1446	0·1457	0·0011	+ 0·77
C. R. No. 42	3	53·4	84·5	1·52	55·0	30·0	0·2038	0·2043	0·0005	+ 0·24
"	4	43·4	78·5	1·70	49·0	22·0	0·1566	0·1582	0·0016	+ 1·02
"	5	15·4	68·5	3·33	68·0	22·0	0·0890	0·1397	0·0507	+56·94
C. R. No. 51	3	45·6	82·0	1·72	59·0	29·0	0·1838	0·1927	0·0089	+ 4·84
"	4	28·6	70·5	2·20	50·0	20·0	0·1117	0·1360	0·0243	+21·75
C. R. No. 125	2	72·0	92·5	1·27	33·0	20·0	0·2857	0·2659	0·0168	− 5·88
"	3	55·4	89·0	1·54	48·0	26·5	0·2924	0·3071	0·0147	+ 5·03
"	4	36·0	85·5	2·16	37·0	13·5	0·1670	0·2057	0·0387	+23·17
C. R. No. 127	5	19·0	61·0	2·84	57·0	20·0	0·1267	0·1826	0·0559	+44·10
Averages .	..	47 0	..	1·82	..	..	..	..	..	+10·08

is omitted, as unnecessary for making comparisons, but the points of cut-off and exhaust, and the actual ratios of expansion, are given. The contents of this Table are based on the average results of detailed Tables compiled for each of the engines named, similar to Table No. II. for the "Great Britain," derived from the evidence of several indicator diagrams in each case, taken from the engines whilst on regular duty. Inside cylinders and outside cylinders are classed separately. The results from the other inside cylinders are corroborative of those from the "Great Britain;" and it is shown that, for an average cut-off of 52·4 per cent., or little more than half-stroke, the average reduction of weight of steam, taken as saturated during expansion, is 6·27 per cent.

With respect to the differences of the weights of sensible steam at the points of cut-off and exhaust, in the inside cylinders, calculated on the supposition that the steam was saturated during the whole period of expansion, the fact that the final weight thus calculated is less than the initial weight is evidence that the steam was, in fact, not saturated but superheated, and that it behaved as a permanent gas during expansion, adiabatically.

The action of the steam in the outside cylinders is broadly distinguished from that of the steam in the inside cylinders. It is shown that, for an average admission of 47 per cent., and an average expansion-ratio of 1·82, there is a positive excess of 10·08 per cent. of steam at the end of the expansion above the initial weight—contrasting with the negative difference for the inside cylinders. But, in four instances of low ratios of expansion, with long periods of admission—of Nos. 13, 33, 41, and 125—the final weight of steam is less than the initial weight. These differences are to be interpreted in exactly the contrary sense to those of the inside cylinders, for they signify that the steam was partly condensed during expansion correspondingly to the condensation already shown to have taken place in outside cylinders in the earlier parts of the expansion period, and which was succeeded by re-evaporation in the later part. It is clearly indicated by the several groups of results for each engine that, whilst the initial weight of steam is reduced, the final excess of weight is absolutely increased. For instance, in C. R. No. 42—

Cutting off at	53·4	43·4	15·4 per cent.
The initial weight of steam cut off is	0·2038	0·1566	0·0890 lbs.
The final excess weight of steam is .	0·0005	0·0016	0·0507 „
Being, in parts of the initial steam .	+0·24	+1·02	+56·94 per cent.

The increase of the weight of re-evaporated steam, previously condensed, at the end of the expansion, in excess of the weight at

the beginning of it, as the steam is cut off earlier and expanded more, in outside cylinders, is graphically represented in the diagram Fig. 9, in which the base-line A B represents the length of the stroke, and is divided into ten parts of 10 per cent. each. The points of cut-off in the third column of Table III., for outside cylinders, are set off on the base-line from B, and from the points so formed ordinates are drawn to the base-line, on which the percentages of excess-weight are set off according to the vertical

Fig. 9.

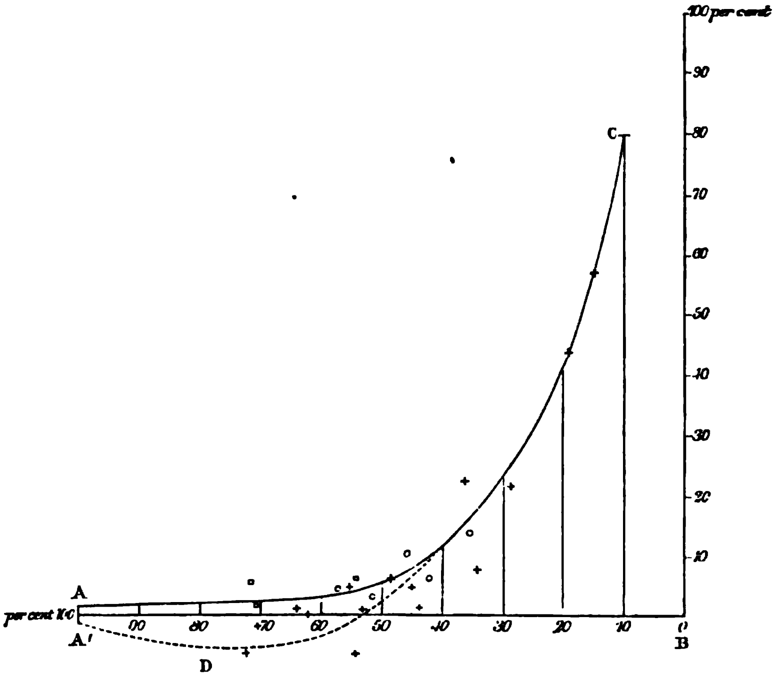


Diagram to show initial Condensation of Steam in the Cylinder, worked expansively.

scale, and indicated by crosses. The medium curve C D A′, traced through these crosses, represents the average indicated excess-weight of steam at the end of the expansion according to the period of admission. The negative excesses, or positive deficiencies, are plotted below the base-line. It is shown that in cutting off at 10 per cent. of the stroke, there is 80 per cent. excess final weight, which diminishes as the period of admission increases, until, in cutting off at 53 per cent. of the stroke, the excess vanishes.

For longer periods of admission, there are deficiencies of weight, as represented by the dotted portion of the curve below the base-line. This curve will bear interpretation. The negative section of the curve indicates positive condensation as well as the positive section, and the curve of actual condensation must be above the base-line for the whole length. The negative quantities marked by crosses may be plotted at equal distances above the base-line, as represented by small squares. There are plotted in addition, marked by circles, five actual results of trials with Nos. 42 and 48 C. R., of which an account will be given. The curve has therefore been rectified by the insertion of the solid line in substitution for the lower part of the curve, forming the curve C A, and interpreting and embodying more directly the experimental facts of condensation.

TABLE IV.—OUTSIDE CYLINDER LOCOMOTIVES C. R.:—INDICATED PROPORTION of STEAM CONDENSED in the CYLINDER for VARIOUS PERIODS of ADMISSION. 1850.

Minimum values, being values as indicated.

Periods of Admission, in parts of the Stroke. 1	Excess Final Weight of Steam, or indicated proportion of Steam condensed, in parts of initial sensible weight admitted. 2	Indicated proportion of Steam condensed in parts of gross indicated weight of Steam admitted. 3	Actual Ratio of Expansion. 4
Per Cent.	Per Cent.	Per Cent.	Ratio.
10	80·0	44·0	4·00
15	57·0	36·0	3·40
20	41·0	29·0	2·85
25	31·0	23·6	2·50
30	23·0	18·7	2·20
35	17·5	15·0	2·00
40	11·0	10·0	1·83
45	7·5	7·0	1·70
50	4·5	4·3	1·60
55	3·5	3·4	1·48
60	3·0	2·9	1·40
70	2·75	2·7	1·25
80	2·5	2·4	1·15
90	2·25	2·2	1·075
100	2·0	2·0	1·00

The Table No. IV. is constructed from the curve as finally settled. For the percentages of admission, in column 1, the excess final

weights of sensible steam, or indicated condensations, are given in column 2, and expressed in parts of the sensible initial weights of steam. Column 3 shows the corresponding values of the excess weights, or indicated condensations, in parts of the gross weights of steam admitted to the cylinder, which is taken as expressed by the final weights, comprising the initial sensible steam plus the positive excess-weight of steam or indicated condensation. This column is intended to show the indicated proportion condensed, of the whole steam admitted. Column 4 shows the corresponding actual ratios of expansion. These were ascertained by plotting the volumes of expansion expressed by ordinates to a base-line representing the length of the stroke, and tracing a curve through them from which the values in column 4 were measured off.

With reference to this Table and the data upon which it is based, the proportions of steam condensed, as indicated, are to be taken as minimum values deduced from the indicated preponderance in weight of steam at the end of the expansion over the weight of steam as cut-off. The actual values for the higher degrees of expansion are certainly greater than the indicated values, for the reasons already given.

"In general, it is to be concluded that, first, when the cylinder is thoroughly immersed in the hot-bath of the smoke-box, the temperature of which is commonly much higher than that of the steam, the quantity of water existing as steam during expansion is virtually constant. Secondly, when the cylinder is placed nearly or entirely beyond the influence of the heat of the smoke-box, or is protected only in the usual manner by felting and plating, the quantity of water or steam varies very considerably during expansion. It suffers a rapid and transient diminution during the first stages of expansion, and remounts to an excess over the initial quantity, which increases uniformly as the ratio of expansion is prolonged; till, for a final volume of about 3½ times the initial volume, when the steam is cut off at 15 per cent., the excess amounts to 57 per cent. of the weight of sensible steam cut off, or, otherwise, to 36 per cent. of the gross quantity of steam admitted.

"The foregoing results are directly contrary to what might have been anticipated, as, at first sight, they appear to show that the less protected the cylinders, the more work is done with a given initial quantity of steam. In the inside cylinder, so far from any apparent evaporation or accession to the total weight of the steam during expansion, the quantity is at least not more than constant, and is, in fact, slightly reduced during expansion. The outside cylinders,

on the contrary, show, by the great excess of steam at the end of expansion, very significant amounts of factitious evaporation.

"In this case, as in that of the low-speed diagrams, the difference is referable to a primary condensation of the steam during admission, by which water is formed, whilst the temperature of the cylinder is raised. After suppression, and when the steam temperature falls by expansion below the newly-acquired temperature of the cylinders, the hot water flashes into steam in virtue of its own heat and that of the cylinder, according to the law of the maximum density and pressure for the temperature; and what appears, at first sight, to have been positively one advantage of an exposed cylinder, in the auxiliary evaporation during the later stages of expansion, is nothing more than a partial resuscitation of the precipitated steam, as a compromise for lost initial action. The greater the proportion of expansion, the greater is the final excess of steam, as the extreme temperatures become more widely different; and, moreover, for the higher degrees of expansion, smaller absolute volumes of steam are admitted, for which there is always the same cooling superficies of cylinder; and this is relatively greater, of course, as the period of admission is reduced. In the enclosed inside cylinder, on the contrary, bathed in hot air or enveloped in cinders, actually hotter than the steam that passes through them, the initial pressure of the steam as it enters the cylinder is maintained in its integrity, as, even for the greater expansions, there appear no symptoms of a resurrection of steam. The evidence goes rather to show that the steam is super-heated during its passage through the steam-pipes previous to admission.

* * * * * *

"Seeing that the indicated expansion-curve leaves us in a state of uncertainty as to the whole loss of effect by condensation, though we know that what we do discover by an examination of the curve is certainly less than the actual loss, we can at present only regard the ordinary loss by initial condensation in outside cylinders, working with 35 per cent. of admission—a common practice on ordinary railways—as at least 15 per cent. of the steam delivered into the cylinder. It is certainly more; and the amount of the real loss is matter for further consideration. To cause initial condensation, it is not even necessary to assume that there is any external dissipation of heat, for, however well a cylinder may be protected from escape of heat externally, it must operate as an equaliser of heat by, in the first place, condensing a part of the steam as it enters, and, secondly, partially

restoring the heat only when the pressure has fallen. It is therefore necessary for the perfect employment of steam in the cylinder to maintain the temperature of the latter at least equal to the initial temperature of the steam by independent means applied without the cylinder, in place of ruinously drawing upon the constituent heat of the steam within.

"These results sufficiently explain how it happens that expansive working in locomotives, especially in outside-cylinder engines, is in practice carried out to such a limited extent. We have rarely found (1850) on the Caledonian Railway—a line stocked with outside-cylinder locomotives—that a cut-off materially less than 30 per cent. of the stroke is voluntarily adopted by engine-drivers. In their own words, they 'lose as much as they gain' if they endeavour to work with a suppression much less than 30 per cent.; and yet it is not easy to conceive a line better adapted than the Caledonian, composed of long and steep double-gradients, for the practice of highly expansive working. The balance of loss and gain above noted is abundantly explained by the extra condensation which attends the earlier cut-off, and is not at all referable to the popular notion that there is something wrong in the nature of the link motion. We may refer to a case in point—the case of the locomotives on that railway, Nos. 25 and 51, taking the same train. As much water was consumed from the tender of No. 51—of which the driver was one of the most economical consumers of coke on the line, and which was worked with variable expansion within the limit already stated—as was withdrawn from the tender of No. 25, an engine worked mostly by the regulator; whereas, steam of a higher pressure, if worked expansively under proper conditions, should have consumed a less quantity of water than wire-drawn steam in the performance of the same duty. There is no doubt that much of the economy of fuel effected with No. 51 was due to the judicious system of stoking practised by the driver, and to his unceasing care in preventing waste of steam at the safety-valve—matters to which little attention was paid with No. 25.

"Nothing is more common than a rush of water when the outside cylinder is tapped for the indicator, whilst the steam is worked with a considerable degree of expansion. With the goods engine, No. 125 C. R., of which the cylinders (Fig. 8, p. 280) are still more exposed than those of No. 51 (Fig. 7), the cylinders during one experiment were never free from a stream of water through the indicator, even for long-continued runs; and during temporary stoppages large accumulations of

water were usually formed, which apparently could never be entirely dissipated, even through the open cylinder-cocks."[1]

Independent evidence of the condensation of steam in exposed cylinders is derived from a comparison of the indicated consumption of steam as cut off, with the measured consumption of water from the tender. For the purpose of testing such comparison, the following, amongst other special trials, were made by the Author, August 29th, 1850, on the actual consumption of water by the outside-cylinder express engine, No. 42, on the Caledonian Railway, for a trip of 105 miles from Glasgow to Carlisle, with a train averaging six and a half carriages, the time of the trip being three hours twenty-two minutes, including five stoppages. Indicator-diagrams were taken from one of the cylinders at intervals of 1 mile or 2 miles, the notch of the expansion-gear was noted for each diagram, and also the points of the line where each change of expansion was made. The periods of admission for the front stroke, measured on slow diagrams taken under steam, are given in the following table, column 2. The admissions for the back stroke were shorter than those for the front stroke, the difference being 1 inch for the first notch, and diminishing towards the fifth notch, or mid-gear, for which the admissions were equal. The mean total admissions, including a clearance of 1·1 inch, and the mean total periods of compression are given in columns 3 and 4. The volume of steam admitted per mile-run under each notch, and likewise the volume shut in and compressed, columns 5 and 6, have been calculated in terms of the area of the piston, the total admissions and compressions in columns 3 and 4, and the number of turns of the driving-wheel in traversing 1 mile of way.

C. R. No. 42, Passenger-Locomotive.

Notch. 1	Admission, Front Stroke. 2	Mean Total Admission, including Clearance. 3	Mean Total Compression, including Clearance. 4	Volume admitted per Mile. 5	Volume compressed per Mile. 6
	Inches.	Inches.	Inches.	Cubic feet.	Cubic feet.
1	14·5	15·1	..	..	..
2	13·0	13·6	4·1	1,558	469
3	11·0	11·7	4·5	1,340	515
4	9·0	9·35	5·3	1,128	607
5	3·4	4·5	8·1	515	916

[1] This and the immediately preceding paragraphs are quoted from the earlier portion of "Railway Machinery," pp. 82–84, published in 1851.

The results of the working of the steam are given in abstract in Table No. V. The trip is divided into four sections, for each of which individually the working of the engine has been analysed. The sections are respectively 16 miles, 15½ miles, 34 miles, and 39½ miles in length, making together the trip of 105 miles.

TABLE V.—WORKING of the STEAM in the PASSENGER-LOCOMOTIVE, No. 42 C. R., with an EXPRESS TRAIN, AUGUST 29, 1850, from GLASGOW to CARLISLE.

Stations, Intermediate Distances, and Times of Steam up. 1	Notch under which the Engine was worked. 2	Miles run under each Notch with Steam on. 3	Average Indicated Pressure per Square Inch. At Cut-off. 4	At Compression. 5
	No.	Miles.	Lbs.	Lbs.
(1.) Glasgow to Motherwell, 16 miles, steam on 30 minutes.	2	½	47	4
	4	5½	36	5
	4	5½	50	5
	4	3	72	5
		14½		
(2.) Motherwell to Carstairs, 15½ miles, steam on 29½ minutes.	3	10	69	4
	3	2¼	38	3
	4	2	50	5
		14¼		
(3.) Carstairs to Beattock, 34 miles, steam on 38¼ minutes.	3	9½	50	4
	4	11	50	5
	4	3	58	5
		23½		
(4.) Beattock to Carlisle, 39½ miles, steam on 56¼ minutes.	2	½	60	4
	3	3	60	4
	3	1¼	30	3
	4	12¾	38	5
	4	2	50	5
	4	1¾	33	4
	4	7½	52	5
	5	3½	30	3
	5	6½	56	3
		38¾		

To calculate the quantity of water as sensible steam, taken as saturated, passed into the cylinder, the volume admitted per mile is divided by the relative volume of the steam according to Mr. Regnault's data, at the pressure when cut off, and the quotient is the equivalent volume as water admitted. Similarly, the quantity of water as steam detained by compression is found by dividing

the volume of steam enclosed by its relative volume. The net volume of water as steam passed through the engine for one end of one cylinder, is the difference of the volumes admitted and compressed. For instance, in the first section, for a length of ½ mile, steam of 47 lbs. pressure is cut off under the second notch, of which the relative volume is 424. The mean volume of total admission per mile-run is, by the Table, p. 291, 1,558 cubic feet; and 1,558 ÷ 424 = 3·68 cubic feet of water as steam cut off per mile. For ½ mile it is (3·68 × ½ =) 1·84 cubic foot of water as steam. The steam compressed in the return-stroke is shut in at a pressure of 4 lbs. per square inch, for which the relative volume is 1,290, and the volume shut in per mile is by Table, p. 291, 469 cubic feet; then 469 ÷ 1,290 = 0·36 cubic foot, and, for ½ mile, 0·18 cubic foot. Deducting the volume thus detained from the volume cut off, the difference is (1·84 − 0·18 =) 1·66 cubic foot of water as sensible steam consumed. Treating in like manner the three other entries in the first section of Table No. V., the results are, in brief, as follows :—

No. 42, C. R., Section (1).

—	Miles Run.	Cut-off Pressure.	Water as Steam, Cut off.	Shut in Pressure.	Water as Steam Compressed.	Difference, Water as Steam Consumed.
		Lbs.	Cubic Feet.	Lbs.	Cubic Feet.	Cubic Feet.
2nd Notch	½	47	1·84	4	0·18	1·66
4th "	5½	36	12·43			
" "	5½	50	15·29	5	6·92	31·78
" "	3	72	10·98			
			38·70			
Water as steam consumed						33·44

The net indicated quantities of water as steam consumed for the three other sections of the trip are calculated likewise. The following Table, No. VI., contains these and other data for comparison. In columns 7 and 8 are given the indicated quantities of steam condensed, being the differences between the quantities of water consumed from the tender, column 4, and the indicated quantities of water as steam cut off, less the steam retained by compression, column 6. In columns 9 and 10 the indicated quantities of steam condensed according to the diagram Fig. 9, p. 286, and the corresponding Table, No. IV., p. 287, are given for comparison with the quantities, columns 7

and 8, as deduced from direct measurement from the tender. The correspondence is very remarkable, and shows as near an

TABLE VI.—WATER CONSUMED and STEAM CONDENSED in the WORKING of PASSENGER ENGINE C. R. No. 42 with an EXPRESS TRAIN, 1850.

Number of Section.	Average Mean Periods of Admission.	Time of Actual Evaporation.	Water Consumed from the Tender.		Net Indicated Water as Steam consumed at Cut-off, less Compression.	Indicated Quantities of Steam Condensed, Difference of columns 4 and 6.		Indicated Quantities of Steam Condensed, according to Table IV., p. 287, column 3.	
			Total.	Per Hour.					
1	2	3	4	5	6	7	8	9	10
No.	Per cent.	Minutes.	Cub. ft.	Cub. ft.	Cub. feet.	Cub. ft.	Per cent.	Cub. ft.	Per cent.
1	42	30	35·82	71·6	33·44	2·38	6·6	3·53	10·0
2	52	29½	48·85	99·4	47·16	1·69	3·5	2·20	4·5
3	46	38¼	67·74	106·2	60·69	7·05	10·4	5·08	7·5
4	36	56¼	79·50	84·8	69·04	10·46	13·2	12·22	16·0
	42	154	231·91	93·6	210·33	21·58	9·3	23·20	10·0

approximation to equality as could in reason be expected under the circumstances. The increase of indicated condensation, column 8, as the period of admission, column 2, is reduced, is apparent. Let the means of sections (1) and (3), which have nearly equal periods of admission, be taken; then, with sections (2) and (4), the following series is obtained :—

Section.	Cut off.	Water Consumed per Hour.	Steam Condensed.	Do. per Diagram and Table IV.
	Per Cent.	Cubic Feet.	Per Cent.	Per Cent.
(2)	52	99·4	3·5	4·5
(1) & (3)	44	88·9	8·5	8·75
(4)	36	84·8	13·2	16·0

The marked variation of condensation with the cut-off inversely, and the close correspondence of the condensations, as calculated in the two modes, from the consumption of water from the tender, and from the internal evidence of indicator-diagrams, Table No. IV., are proofs of the fact of the condensation of steam in the cylinder, in consequence of expansive working, and of the soundness of the method adopted, as far as it goes, for calculating the quantities condensed. The suggestion that the deficiency of water as steam indicated is caused by priming is not sustained by the evidence,

for the deficiency is less as the rate of consumption of water per hour is greater; whereas, if it had been caused by priming, the deficiency would have been increased with the rate of consumption.

The results of the performance of another locomotive on the Caledonian Railway, No. 48, of the class of No. 42 just noticed, may be given. This engine was run, March 27th, 1850, with a coke-train up Beattock incline, which is nearly 10 miles long, and of gradients varying from 1 in 88 to 1 in 75. The ascent was performed in twenty-nine and half minutes, and 42·7 cubic feet of water were consumed from the tender. The engine was worked for 3 miles in the first notch, and $6\frac{7}{8}$ miles in the third notch, cutting off at 15·7 inches and 11·25 inches, and shutting in for compression at 1·15 inch and 3·01 inches. Adding 1·1 inch of clearance, the volumes of steam admitted per mile were 1,809 cubic feet and 1,415 cubic feet respectively; and, compressed, 258 feet and 471 feet. The pressures at cutting off were 50 lbs. and 66 lbs. per square inch; and, for compression, 3 lbs. The quantity of water as steam consumed, as indicated, was 41·09 cubic feet. Then—

	Cubic Feet.
Water consumed from the tanks . . .	42·70
Indicated water as steam consumed . .	41·09
Difference, steam condensed . . .	1·61 or 3·77 per cent.

The average period of admission was $11\frac{1}{2}$ inches of the stroke of 20 inches, or $57\frac{1}{2}$ per cent. For this admission, the indicated proportion of steam condensed, according to Table No. IV., p. 287, is 3·15 per cent., whilst the result of the trial shows a loss of 3·77 per cent., showing, though not equality, a near and instructive correspondence.

The foregoing are results of the Author's experimental investigations on the working of steam expansively in locomotives, drafted from his Paper of 1852, already referred to, as well as from the portion of his work on "Railway Machinery," published in the course of 1851.[1] These conclusions on the alternate condensation and re-evaporation of steam in cylinders are now universally accepted; but it does not appear that they were fully appreciated for some years after they were published.

[1] Whilst the original matter, and the course of investigation originally adopted, have been given, all the calculations and tables, based on the properties of steam have been made anew and recast, in the light of the more recent experimental investigations of Mr. Regnault into the constituent heat and density of steam.

Three or four years later, in 1855, Mr. G. A. Hirn published results of his investigations of the action of the steam-jacket.[1] In this Paper he does not make any reference to the action of the material of the cylinder in alternately condensing and re-evaporating steam worked expansively. He simply seeks to establish "that if the steam does not occupy the volume due to its density and pressure, this is due to its being partly condensed into water," and that the steam-jacket, heating the walls of the cylinder, diminishes the quantity of such partial condensation. In his next Paper, dated October 29th, 1856, published in 1857,[2] he publishes the results of experimental investigations made by him since the reading of his Paper in 1855, in which he, for the first time, apprehends the fact of the alternate condensation and re-evaporation of steam worked expansively in the cylinder, and establishes it in his own manner. He notes that absorption of heat and re-evaporation are continued to the end of the stroke, after the exhaust is opened to the condenser, when expansion and lowering of temperature of the steam in the cylinder are continued. This continuation of the re-evaporative action, which is a very natural deduction, is the only new feature in Mr. Hirn's deductions on the alternate condensing and re-evaporating process in the cylinder, inasmuch as he had clearly been anticipated by the Author in the demonstration of the fact, and the causes, of the alternate condensation and re-evaporation during the period of expansion, on the evidence of the indicator diagram, and the practical working of locomotives.

Mr. Hirn defined such reactions with a greater degree of precision in 1862.[3] "The steam," he says, having assumed, for example, that it is cut off at one-fifth, "flows from the boiler to the cylinders during one-fifth of the stroke of the piston, from each end of the cylinder. During this part of the stroke the cylinder-cover, the face of the piston, and the corresponding portions of the walls of the cylinder, are necessarily raised to the temperature of the steam, and steam is condensed until this condition is fulfilled. When the steam is cut of and exhaustion begins, the steam falls in temperature, and absorbs heat from the previously heated portion of

[1] "Mémoire sur l'Utilité des Enveloppes à Vapeur," dated April 25th, 1855, published in the "Bulletin de la Société Industrielle de Mulhouse," 1855, vol. xxvii., p. 105.

[2] "Mémoire sur la Théorie de la Surchauffe dans les Machines à Vapeur," in the "Bulletin de la Société Industrielle de Mulhouse," 1857, vol. xxviii., p. 5.

[3] "Exposition analytique et expérimentale de la Théorie mécanique de la Chaleur," Editions of 1862, 1865, and 1876.

the cylinder. As the piston advances, the steam parts with heat to the newly-exposed parts of the cylinder, whilst it absorbs heat from the previously heated portions. After passing the middle of the cylinder, the steam meets with the portion towards the other end of the cylinder that had been heated during the previous stroke. When the piston has arrived at the end of the stroke, the steam is exhausted into the condenser, and during this new expansion it absorbs heat from the whole of the surface of the cylinder exposed to it, varying in quantity according to the rapidity of the exhaust, being greater in proportion as the outflow is slower." Here, as in Mr. Hirn's Paper of 1856, there is nothing new, in respect of the subject of the Author's investigations, except the statement of the continued absorption of heat and re-evaporation of steam after the exhaust is opened to the condenser.

The existence, then, of alternate condensation and re-evaporation of steam in the cylinder had been experimentally demonstrated by the Author many years before Mr. Hirn had even suspected their existence. It must, nevertheless, be stated that Mr. Hirn has reduced the process of test-experiments on steam-engines to a system remarkable for precision and for the success with which the mechanical equivalent of heat is employed as a factor.

Chief Engineer B. F. Isherwood, of the United States navy, published, in 1863,[1] the results of experiments made by him in 1860, in which he accounts for the inferiority of the quantity of water as steam cut off, measured by the indicator, to the quantity of water delivered to the boiler and passed through the engine. He does so on the principle of the alternate condensation and re-evaporation of steam in the cylinder, the evaporation continuing after the exhaust is opened to the condenser. This explanation, of which he claims to be the discoverer and demonstrator, is identical with that which had previously been announced, first by the Author, and secondly by Mr. Hirn; and it was published thirteen years after the Author had published his own experimental conclusions, establishing the same principles of action, and accounting for the difference of the indicated and measured quantities of water consumed in the same way. Nevertheless Mr. Isherwood, fifteen years later, in 1878,[2] continues to claim priority of discovery. "The writer also first showed," he says, "that when steam was used expansively, the cylinder acted both as a condenser and as a boiler:

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[1] "Experimental Researches in Steam Engineering," vol. i., 1863, p. 29.

[2] "Expansion of Steam in the Steam Engine," in the "Journal of the Franklin Institute," 1878, vol. cvi., pp. 2, 3.

as a condenser during the portion of the stroke of the piston preceding the closing of the cut off or expansion valve, and as a boiler during the remaining portion of the stroke; part of the water of condensation deposited on the cylinder surfaces during the first portion of the stroke, vaporizing during the last portion by its contained heat and the heat of the metal of the cylinder under the continually decreasing pressures due to the continuous expansion of steam. Whatever water of condensation remained when the piston reached the end of its steam-stroke, vaporized during its exhaust-stroke under the still lower condenser pressure, so that when the steam-valve again opened to admit steam from the boiler to the cylinder, the whole of the steam which had been condensed in the latter had been re-evaporated and passed over into the condenser. The writer," he adds, "not only stated these facts qualitatively, but gave, by means of his experiments, very exact quantitative measures," &c. These researches, it may be seen, are mere repetitions of those of the Author, published in 1851 and 1852.

Such are, in brief, the evidence and arguments employed and published by the Author in 1851–52, in investigating the behaviour of steam in the cylinders of locomotive steam-engines, showing, amongst other things, the formidable losses by condensation and re-evaporation of steam in cylinders, and the augmentation of loss in proportion to the degree of expansion to which the steam is worked; and showing that without the adoption of special means for preventing condensation within the cylinder, expansive working, by cutting off earlier than at from one-half to one-third of the stroke, could not be practised with economy.

The Author takes this occasion to confirm his priority in experimentally demonstrating the pregnant fact of alternate condensation and re-evaporation of steam in the cylinder, quantitatively, as well as qualitatively, and the consequences thereof, because the claims to priority on the part of Mr. Isherwood, as well as of Mr. Hirn, have been for many years placed well before the public. It is a question of chronology, and does not admit of disputation. A disinterested authority, Mr. Anatole Mallet, Past-President of the Institution of Civil Engineers of France, has kindly recognised the Author's priority on this question, in his communication to that Institution in 1877, on the utilization of steam in locomotives.[1]

[1] "Étude sur l'Utilisation de la Vapeur dans les Locomotives et l'Application a ces Machines du Fonctionnement compound," in the "Mémoires de la Société des Ingénieurs Civils," 1877. In this Paper, Mr. Mallet says: "Mr. D. K. Clark was

the first experimentalist who, by practical evidence, traced to its true source the excess of the quantity of steam, or the water-equivalent of it, in the cylinder, at the end of the expansion. He demonstrated that a portion of the steam when admitted at each stroke was condensed, and that it was in part re-evaporated at the end of the expansion; and that by this destroying process the efforts at economy by cutting off early and expanding were baffled, insomuch that it was practically impossible with economy to cut off earlier than at one-third of the stroke." Mr. Mallet proceeds to say: "In these publications (already named in the foot-note, p. 276) has been for the first time so completely elucidated the behaviour of steam in the cylinders of locomotives, and the part that is played by the condensation of the steam during admission—a characteristic phenomenon which gives the key of the difference which always exists between the practical expenditure of engines and the calculated consumption, and the reality of which, strange to say, many engineers, otherwise very distinguished, really believed could be contested ten or twelve years after the publication of those works" (p. 852).

See a series of articles, in behalf of Mr. Hirn's claim, on "Les Découvertes récentes concernant la Machine à Vapeur" (Recent Discoveries in the Steam-Engine) by Mr. V. Dwelshauvers-Dery, in the "Revue Universelle des Mines," tomes iv., v., and vii., for 1878, 1879, and 1880. Also several contributions by Mr. O. Hallauer and others to the "Bulletin de la Société Industrielle de Mulhouse."

OBITUARY NOTICES.

Mr. THOMAS LONGRIDGE GOOCH was one of that great school of Tyneside engineers created by George Stephenson, and destined more or less to share with him the triumphs and the disappointments which preceded the general introduction of the railway system. Owing to his enforced retirement from the profession at the early age of forty-two, Mr. Gooch had long outlived his reputation as an engineer; but in the exciting days of the railway mania his name was prominent and ranked second only to that of the Stephensons and Brunel, and had health allowed him to continue his active career, he would doubtless have achieved the fullest honours which the profession could bestow. As it was, he had to be content with a life of private usefulness, in the dignified leisure of which he could, as one of his contemporaries [1] afterwards expressed it, replace the brilliant anticipations of hope by the more sober pleasures of memory.

Thomas Longridge Gooch was the eldest son of John and Anna Gooch, and was born on the 1st of November, 1808, in London, where his parents were temporarily resident. When he was about seven years old his father obtained the appointment of cashier to the Bedlington Ironworks, and it was in that neighbourhood, in the village of Crowhall, that young Gooch received the chief part of his school-education. Here he enjoyed, to the fullest extent, the advantages of outdoor exercise, involved in long walks to and from school, although in summer time his 3½-mile trudge by Hartford Bridge could be considerably shortened by the use of stepping-stones across the River Blyth. Latin and Greek were not taught him, but he made pretty good progress in arithmetic and geometry, with a commencement in algebra. During the latter portion of his schooldays he used frequently to walk on Saturdays 24 miles, to Newcastle and back, to take drawing-lessons.

On the 6th of October, 1823, being nearly fifteen years of age, he was bound apprentice for six years to George Stephenson, and entered the factory, then in course of erection, in South Street,

[1] Mr. Charles Vignoles in his inaugural address as President of the Inst. C.E., Jan. 11, 1870.

Newcastle-on-Tyne. Young Gooch remained in the shops for two years, receiving wages of 8*d.* a day, afterwards increased to 1*s.* a day. He then passed on to the drawing-office and was engaged there, and in assisting to take levels and make plans in reference to a projected railway between Newcastle and Carlisle. In this work his companions were Joseph Locke,[1] William Allcard, and Hugh Steel, Locke having the direction of the work. During this year (1825) George Stephenson was greatly occupied with the Liverpool and Manchester railway scheme, and the rejection of the Bill by Parliament was probably the severest trial he ever experienced. In the interval between this and the renewed application for the Bill, Mr. Stephenson allowed Gooch to spend some months at Edinburgh University, chiefly with a view to study chemistry; but, as it was not the proper time of year for the regular classes, he did not get the full benefit of the visit. Nevertheless he obtained some knowledge of the chemistry of that day, and also imbibed a taste for geology, which continued through life, and afforded him many a day's pleasure and enjoyment.

On his return from Edinburgh, in September 1826, he passed a few weeks at home, and during this time received his first payment as a draughtsman, Mr. Michael Longridge, the manager, presenting him with £5 for the copy of a plan of the Bedlington Ironworks. The Act for the Manchester and Liverpool railway was obtained in 1826, after a severe fight with the landed interest and the canal companies, who were finally conciliated by substantial concessions, and George Stephenson was again appointed engineer (having been temporarily superseded by the Messrs. Rennie). Young Gooch, then just eighteen years of age, was summoned to Liverpool to join his chief, in whose house at Windsor, Upper Parliament Street, he resided. Here for two years and a half he acted as George Stephenson's secretary and draughtsman. He made nearly the whole of the working and other drawings, as well as the various land-plans, for the Liverpool and Manchester railway, at the company's office at Clayton Square, Liverpool, during the day, from instructions supplied in the evening by Mr. Stephenson, either by word of mouth, or by little rough hand-sketches on letter-paper. The evenings were also devoted to his duties as secretary in writing Stephenson's letters and reports, or in making calculations and estimates. Mr. Gooch's diary records that it "was a busy time for us all, and a most anxious one for George Stephenson. So much was new and untried in the railway

[1] Afterwards President of the Inst. C.E., and M.P. for Honiton.

itself, and still more as respects the locomotive engine, which had a hard struggle to obtain that favour with the Directors of the railway which it possessed in the mind of George Stephenson."

Gooch fulfilled these duties until April 1829, when he was sent, as resident engineer, to the unfinished Bolton and Leigh railway, where he remained till the completion of that little branch-line in the autumn of the same year. He then went to live at Newton-in-the-Willows, to be near a new branch-railway from Newton to Warrington, to which he had been appointed resident engineer under Robert Stephenson, but remained only long enough to assist in the completion, by tremendous exertion, of the parliamentary plans and sections before the statutory time of deposit. The Newton and Warrington extension, which constituted the first step for a line from Liverpool to Birmingham, was, however, not proceeded with; and Mr. Gooch returned again to Liverpool, having been appointed from the 1st of January, 1829, resident engineer of the Liverpool end of that line in succession to Joseph Locke. Mr. Gooch held this charge until one month after the completion and opening of the line. His diary states:—

"The portion of the Liverpool and Manchester railway under my charge extended from Liverpool to near the Sankey Viaduct (about 13 miles), and every possible exertion was needed to complete the works of the great Mount Olive cutting in time for the proposed opening of the line in the autumn. But the most anxious part of my duties were the novel, harassing, and lengthened preparations and experiments necessarily connected with the general opening of the line, which, from being at the Liverpool end, as a matter of course fell upon me. The workshops and stock of engines, carriages, and wagons, were all at Liverpool, where George Stephenson resided, and where the Board of Directors met. Here it was that, under the direction of Mr. Stephenson, I had to make all the preliminary arrangements and experiments for the conduct of the traffic, and the conveyance, for the first time, of passengers at the rate of 30 miles an hour!—a velocity which had taken everybody by surprise, and needed much thoughtful preparation for its safe conduct. For this purpose many preliminary experiments were made, in order to test all the various details of the arrangements. Every week, for ten or eleven weeks previous to the opening, we made trial trips to Newton or to Manchester and back, generally with two or three trains at a time, conveying in all from 150 to 300 persons. Saturday afternoon was usually chosen, as the works might then be stopped, and the line cleared as much as possible for the occasion. But to do this effectually,

and to arrange the numerous and very imperfect points and crossings in use by the contractors executing the works, so as to feel satisfied as to safety, was no easy task."

The public opening of the Liverpool and Manchester Railway forms a chapter in the history of the century, and is too well known to be dwelt upon in this memoir. It must therefore suffice to state that Mr. Gooch was a prominent actor in the ceremony, having charge of the "Dart" locomotive, drawing one of eight trains of which the procession was composed.

The successful inauguration of this line induced an era of great activity in railway engineering, and Mr. Gooch was speedily offered the entire charge, under George Stephenson, of a projected line from Manchester to Leeds. In those days the 30th of November closed a season of even more fevered haste and scramble than is the case at present, and Mr. Gooch's diary shows that its writer experienced his full share of the amenities consequent on field-work all day, and plotting the results and drawing plans all night. In the case of the Manchester and Leeds survey, the last testing of the levels, which he did himself by comparing them with the summit-level of the neighbouring canal, had to be done by torch-light in the field; and the plans, sections, and books of reference, were only lodged at Wakefield and at Preston a few minutes before the clock struck midnight, and that by the aid of a carriage and four horses to each place. The occasion of the Bill for the Manchester and Leeds railway reaching committee was Mr. Gooch's first appearance as a parliamentary witness. Fortunately he had made himself thoroughly acquainted with the details of the survey, and, although some confusion or trepidation might have been excusable in one so young, he came off with flying colours, and, on leaving the witness-box, he was warmly congratulated and shaken by the hand by all those Directors who were present in London watching the progress of the Bill. Although the preamble of this Bill was declared not proven in 1831, it was resolved to repeat the application in the following session, Mr. Gooch being reappointed engineer. For some months after this he was nearly idle, but in October received a summons from Mr. Robert Stephenson to assist in preparing the plans and sections of the proposed London and Birmingham railway. In this work he was associated with Mr. Frank Forster, M. Inst. C.E., and Mr. Thomas Elliot Harrison, Past-President Inst. C.E., and with them took, in a period of six weeks, the whole of the levels for that celebrated line, without reference to what had been done the year before. Lithography was not then applied to this kind of work, although

the strictest accuracy was demanded by Parliament. Nine or ten copies (in duplicate) of the plan and section were wanted. The accuracy of the sections was especially necessary, and Mr. Harrison and Mr. Gooch undertook and finished these entirely with their own hands, tracing them through glass plates inserted in the drawing-boards, with lamps giving a strong light underneath. This tedious labour occupied night and day for about a week; it was done at the office of Mr. John Sanderson, brother-in-law to Mr. R. Stephenson, in Broad Street, London. Though Mr. Gooch took lodgings near at hand, he left them without ever having been in bed during the week, to the astonishment of the landlady. The work was completed by the 25th of November, when a gathering of all hands took place at Stoney Stratford, where plans, sections, and books of reference were completely finished and thoroughly examined. This again involved almost constant night-work, but all the documents were very satisfactorily lodged on the 30th as required. The interval until the middle of February 1832, was occupied in preparing at Newcastle the estimates for the whole work, and a month later Mr. Gooch accompanied Mr. R. Stephenson over the country, *via* Tring, Banbury, and Warwick, noting it closely, so as to be prepared for a cross-examination on this rather more direct route, which it was rumoured was to be used against them by the allied canal- and landed-interests. Although every precaution was taken which prudence and foresight could suggest, the Bill was thrown out by the House of Lords on the ground that the dissenting landowners were in the proportion of 59 miles to 53. This involved a repetition of the work of the previous autumn, with the result of getting up the case in greater detail. This time Mr. Edward Dixon, M. Inst. C.E., was associated with Mr. Gooch. The Act for the London and Birmingham railway was obtained in April 1833, Mr. Gooch was appointed resident engineer to about 36 miles at the north end of the line, or from Birmingham to Kilsby Tunnel, and on the 23rd of the following October he took up his quarters at Coventry.

This closed the most exciting and interesting part of Mr. Gooch's working career. He had been worthily associated with the two great railway enterprises which have become household words in the history of engineering, and his rapid and continuous advancement was a necessary consequence. The remainder of his professional life was that of a prosperous, influential, and highly respected engineer. After he had been for two years on the London and Birmingham works, a deputation of the resuscitated Manchester and Leeds line waited upon the London and Birming-

ham board, with a request that Mr. Gooch might be allowed to lay out the line and prepare the scheme for Parliament. At first this was only a temporary transfer, and after the lodgment of the Bill he returned to his duties on the London and Birmingham; but eventually he was appointed joint principal engineer (with George Stephenson) of the Manchester and Leeds line, and took up his residence in Manchester. The works of this railway were of an unusually heavy character, including a summit-level tunnel nearly 1⅝ mile long, through a portion of Blackstone Edge, and the line had been described as the (then) "greatest triumph of engineering science over the obstacles interposed by nature presented by any railway in the kingdom." The Manchester and Leeds Railway was opened on the 1st of March, 1841, and the Directors presented Mr. Gooch with a sum of £1000, in token of their approval of the manner in which the works had been successfully completed; but the value of this compliment was exceeded, in his estimation, by a testimonial from the whole of his staff, consisting of an address and a handsome tea-service.

On the completion of the line Mr. George Stephenson retired, Mr. Gooch remaining alone as principal engineer, and remaining in that office for three years, chiefly occupied in winding-up the heavy contracts in connection with the main line, and in the construction of branches. An interesting and, perhaps, unique circumstance occurred about this time, which will serve to show the confidence Mr. Gooch inspired in railway magnates. Among many similar applications, he was asked to lay out a line to be called the Manchester, Bury, and Rossendale Railway. This he did, with the full consent of his Directors; but at the eleventh hour they resolved to start a line of their own in competition with it, which they called upon Mr. Gooch also to lay out. This, of course, placed him in an awkward position, and he proposed at once to retire from both projects, but he was requested by the parties on both sides to continue, so he laid down for each the best line he could select. A severe struggle took place in the House of Commons, in which, though he was present in Committee, he took no part, other engineers being called in to give evidence. It ended in a decision by the Committee in favour of the Rossendale line. In June 1844 Mr. Gooch retired from the Manchester and Leeds Railway. A month later he received a kind letter from his friend, Mr. Joseph Locke, offering him to become joint engineer with Mr. Locke of the great project of the day, the London and York Railway. This was a strong temptation to him, but the consideration that it would necessarily place him in a hostile position

to the Stephensons and the London and Birmingham interest led him ultimately to decline the offer. However, by this time the railway mania was in full swing, and Mr. Gooch speedily found himself solicited on every side to lay out new lines, insomuch that, although using great discrimination in the projects he associated himself with, he soon found his hands full. At the time these schemes were only in the parliamentary stage, the Manchester, Bury, and Rossendale (to which he had succeeded Mr., now Sir John, Hawkshaw) being alone in actual construction. Of all these undertakings the most important was the Trent Valley, of which he was "joint principal engineer" with Mr. Robert Stephenson and Mr. G. P. Bidder. At the turning of the first sod of this line on the 13th of November, 1845, Sir Robert Peel, then Prime Minister, made a speech which it was generally thought greatly increased the force of the railway mania. Shortly previous to this, Mr. Gooch had been invited by the East India Company to go to India in a very high and responsible position, with a view to the introduction of railways into that country; but, though the appointment would have been a most lucrative one, he decided not to accept it, being influenced mainly by family reasons, and by the state of his health. This latter consideration was of greater importance than he had at first attached to it, for the strain of years of almost ceaseless hard work had begun to tell seriously upon him. From his diary it appears that for nearly twenty years his only real holiday was a three days' honeymoon when he was married; and though when he retired from the Manchester and Leeds Railway, he had proposed to seek some relaxation in the Lake District of England, he had scarcely reached Bowness before being called away again to resume his labours in the committee-rooms, and more and fiercer contests than he had yet experienced. These brief rests, added to a fortnight's trip up the Rhine a year or two later, were not sufficient to repair the waste of brain-power entailed by an enthusiastic love of the profession. In August 1847 Mr. Gooch was suddenly taken ill in the office at 24 Great George Street, and the doctor at once prescribed an entire cessation from work. Mr. Gooch went to Dawlish, where he remained quietly for about a month; but, finding he was too near his work, he was recommended to leave England. In the result, he passed the winter at Pau with his family, and making a long round homewards in the following spring, arrived in England very much better, after eight months' complete holiday. Mr. Gooch then resumed his profession for two or three years. In the meantime the bubble of the railway mania had burst, and new

schemes were few, so that he had more leisure than ever before in his life. But despite this his health continued to decline, and in 1851, at the early age of forty-two years, he was compelled to retire from a profession most congenial to his taste, and in which he had risen to a position in the first rank.

The concluding pages of a most interesting MS. autobiography, from which this memoir has been abridged, contain a simple and unaffected expression of his sorrow at this premature close of his active career, the almost pathetic nature of his regrets being only equalled by the modest way in which he refers to his achievements, and the thankful spirit in which he records that his savings had been sufficient to secure him at moderate interest an ample competence.

Dropping thus quietly out of active life, Mr. Gooch purposed to devote the remainder of his days to benevolent objects. His contributions to charitable objects were liberal, and given in most cases anonymously. He was a man of unpretending manners and kindly disposition, who made friends of all with whom he became acquainted. For several years he had been a manager of the Carus Wilson Soldiers' Aid Society, the founder of which devoted his life to the welfare of soldiers, especially of those on foreign stations. In this work Mr. Wilson associated with him a number of ladies and gentlemen, among them being Mr. Gooch. On his deathbed Mr. Wilson solemnly handed over the charge of the Society to Mr. Gooch, who from that time zealously attended to its affairs. For many years his duties as manager obliged him to carry on a large correspondence with all parts of the globe on matters relating to the circumstances of soldiers and sailors. In a quiet way, unknown mostly to the public, he and his volunteer helpers have carried on a work of charity, the good effects of which have been felt in all parts of the world to which the British soldier or sailor finds his way. He was a member of the Literary and Philosophical Society of Newcastle, and was until a short time before his death to be seen every day in its library in Westgate Road. He was deeply interested in the Stephenson Centenary celebration at Newcastle a year ago, but through infirmity he was unable to take part in the proceedings. He was urged to make an appearance on that day, but his reply was to the effect that, being up in years, he did not again wish to mix with the bustle of the world.

The usual limits of an obituary notice in these volumes have been exceeded in the case of Mr. Gooch, as one of the very few men who in their own persons took part in the birth, the adolescence,

and the full maturity of the railway system, from the horse-worked Stockton and Darlington Line of 1825, to the inauguration of the Britannia Bridge. This last marks the second period in the history of engineering, as the canal-system and reclamation works of the latter half of the eighteenth century noted the first, and in connection with it the sterling merit of Mr. Gooch is entitled to full recognition. Beyond his technical qualifications as an engineer, as a man of business he was distinguished by cool judgment and deliberation. His almost romantic devotion to the Stephensons, father and son, met with a warm return. The friendship between them was steady and unbroken for nearly forty years, marked by strong affection, sincere respect, and mutual reliance. Towards the close of Robert Stephenson's life, Mr. Gooch, having returned home after a long absence on the Continent, had the satisfaction of spending with his family four happy months under his friend's hospitable roof in Gloucester Square; and, at Mr. Stephenson's earnest request, Mr. Gooch accompanied him on his last visit to Norway.

Mr. Gooch was elected a Member of the Institution on the 3rd of June, 1845, but did not take any active part in its proceedings. The establishment of the Benevolent Fund in connection with the Society secured the thorough sympathy of his warm heart, and he was one of the most liberal donors to its capital fund.

This excellent engineer, good citizen, and virtuous man, passed quietly away on the 23rd of November, 1882, in his seventy-fifth year, his peaceful end a fitting sequel to a well-spent life.

MR. ROBERT ROWAN GREENE, son of the Rev. Robert B. Greene, rector of Killodiernan, county Tipperary, was born in 1835, and educated under the Rev. Mr. Bullen, of Nenagh.

Deciding to become a Civil Engineer, he, at the age of seventeen, went to Canada to be trained for the profession, under the supervision of his cousin, Mr. Frederick Rowan, then Chief Engineer of the Grand Trunk Railway of Canada. After being with Mr. Rowan for three years, he returned to England, and resumed his studies under the late Sir John McNeil, M. Inst. C.E., and, during the three years he remained with that gentleman, took part in the construction of the County Down Railway and the Dublin and Meath Railway. In 1858 he went to the late Mr. Edward Wilson, M. Inst. C.E., then Chief Engineer of the Great

Western, Great Eastern, and other railways; and while with Mr. Wilson he carried out several works of importance, among them being the construction of the Stourbridge and Birmingham Railway, the Great Eastern Metropolitan Extensions, the Netherton and Halesowen, the Bewdley and Kidderminster, and other lines. On the death of Mr. Wilson, Mr. Greene remained with the firm of Edward Wilson and Co. (who succeeded to the practice) until 1878.

In 1878 he was elected, from among a hundred competitors, to the position of Chief Engineer to the Midland Great Western Railway of Ireland, and the Royal Canal, and this post he retained until his death, which occurred on the 18th of November, 1882. During his service with the Midland Great Western Company he devoted his whole attention, with untiring energy, to its affairs. In that period over 200 miles of the line were relaid with steel rails, and most of the large stations were supplied with new interlocking signal apparatus, from plans prepared by Mr. Greene. Several of the large stations, including the Broadstone Terminus, Dublin, and the Mullingar, Athlone, and Athenry Junctions, were also remodelled under his direction. A new avenue of approach to the Broadstone Terminus was made, and this involved the removal of an aqueduct and the filling up of a portion of the harbour of the Royal Canal, which was in close proximity to the railway. All these works were designed and carried out by Mr. Greene with complete success, and to the satisfaction of those concerned. The plans for a new branch railway, now about to be constructed, between Crossdoney and Killeshandra, in the county Cavan, were also prepared by him a short time before his death.

Mr. Greene was essentially a practical engineer. He was thoroughly conversant with all the details of his profession, and whatever he undertook he always carried out well and carefully. His genial and kindly disposition won for him many firm friends, and his death, on the 18th of November, 1882, at the early age of forty-seven, caused heartfelt grief to all who knew him.

He was elected a Member of the Institution on the 2nd of April, 1878.

MR. WILLIAM BEATTIE was born at Liverpool, on the 11th of December, 1836, and was educated at a collegiate school in the town. From 1849 to 1852 he served in machine and railway carriage-building shops, under his father, at Liverpool, and was then employed at the Dallam Ironworks, Warrington, until 1855,

during which period he was engaged chiefly in the forges where the manufacture of railway wheels, axles, and tires was carried on. In 1855 he entered the service of the London and South-Western Railway Company at Nine-Elms works, under his uncle, the late Mr. Joseph Hamilton Beattie, M. Inst. C.E., and was employed in the drawing-office and workshops as one of the principal assistants to the locomotive and carriage superintendent of the Company, in the working of the railway, and in the general arrangement of the business of the department. He was officially appointed Assistant Locomotive- and Carriage-Superintendent in August 1881, and held that position until his death, which occurred on the 19th of December, 1882.

Mr. Beattie was elected an Associate Member on the 6th of May, 1879. He bequeathed fifty guineas to the Society.

MR. WILLIAM JOHN BOYS, son of Mr. John Boys, timber-merchant and contractor, was born at Walsall in 1840, and was educated at Queen Mary's Grammar School in that town.

He began his career as an assistant in the service of the Birmingham Canal Navigation Company, and was, whilst with them, engaged on several important engineering works; and was afterwards employed by Messrs. M'Clean and Stileman on the South Staffordshire Waterworks. In 1865 he was appointed Assistant Surveyor of Walsall, under Mr. Clark, the then Surveyor to the Improvement Commissioners; and, on the death of Mr. Clark about a year after, Mr. Boys was appointed his successor. From that date he designed and carried out many important works in the town, and was greatly instrumental in introducing into his district the Artisans Dwellings' Act. The large sewage-scheme now being proceeded with was designed by him, his plans being successful in public competition.

Mr. Boys was elected an Associate Member on the 6th of February, 1877. He died on the 21st of December, 1882.

SAMUEL DOWNING, LL.D., late Professor of Civil Engineering in Trinity College, Dublin, was the son of the Rev. Samuel Downing, rector of Fenagh, diocese of Leighlin. He was born at Bagenalstown, county Carlow, 19th July, 1811, and was educated at Kilkenny College, a public school, rendered famous

by its having numbered among its scholars Bishop Berkeley and Dean Swift; but now, like many other schools in Ireland, in a low condition, owing to the apathy and neglect of the gentry. He entered Trinity College in January 1829, and took the degree of B.A. in 1834. Shortly after, he repaired to Edinburgh for the purpose of attending lectures in Natural Philosophy, which included many of the subjects now taught in the recognised course of engineering. Having availed himself of this opportunity, he worked for some time under Mr. Hughes, of Northampton, who held several railway contracts. He afterward acted as resident engineer under Mr. Bushe, and had sole charge of works executed by that engineer; among these may be noted the timber viaduct, 560 feet long, connecting Portland Island with the mainland, and costing, with the approaches and toll-house, only £4,000. He was also employed in the construction of the curved viaduct at Coed-re-Coed, on the Taff Vale Railway. This structure consisted of six arches of 50-feet span, at a height of 106 feet over the river Taff. In 1847 Dr. Downing was induced to leave the active work of his profession, when he was appointed assistant to Sir John MacNeill, who had been nominated Professor of Engineering at the formation of the School of Engineering in Trinity College in 1842. In 1852 Dr. Downing became Professor, and occupied the chair until his death. During that period nearly four hundred students passed through the school, many of whom have attained eminent positions in the profession. All of these can testify to his great skill as a teacher. His intercourse with his pupils, which was never interrupted during this long period for a single day, was characterised by punctuality, patience, and unwearied industry, in imparting to them his varied stores of knowledge. It may be safely said that few men have passed so many years in any public institution and left behind him, both among students and colleagues, a memory so beloved as Samuel Downing.

Besides several Papers written for scientific societies, Dr. Downing published some very valuable works, which have passed through several editions; among which may be mentioned his well-known "Elements of Practical Hydraulics," "Elements of Practical Construction," and his "Selection of Specifications of Public Works"; this last being particularly intended for the use of his pupils.

Dr. Downing was elected an Associate of the Institution on the 2nd of March, 1852. He died on the 21st of April, 1882.

Mr. EBENEZER GODDARD, son of Mr. Daniel Poole Goddard, was born at Ipswich on the 10th of March, 1816, and was educated at Halesworth, Suffolk, at a noted school, at which the majority of the superior class of youths of that county then received their education. In due time he was apprenticed to Messrs. J. R. and A. Ransome, the well-known agricultural engineers of the Orwell Works, Ipswich.

On the completion of his time he resolved to go to London, where only, he considered, a thorough knowledge of mechanical engineering could be acquired, and shortly after his arrival he was engaged as a journeyman at the General Steam Navigation Company's works at Deptford.

A few persons are still living who remember the period when the principal available power in an engineer's shop was obtained by one, two, or more men turning a fly-wheel, which gave motion to the lathe; and they will also remember the arrogance, conceit, tyranny, and spirit of exclusiveness which pervaded the working engineers of that time, and for many years after. Thus, although steam-power had been adopted at least twenty years before young Goddard entered the service of the Steam Navigation Company, the old jealousy still survived, and the men, learning that he had not been apprenticed to a regular steam-engine-fitting firm, at once insisted on his dismissal, and if the unjust demand had not been complied with, a general strike would have been the result.

At that period the terminus of the Great Western Railway was at Maidenhead, where the Company also had extensive workshops for repairing locomotives and similar work; and here the subject of this memoir worked for some time, always anxious to make himself thoroughly master of all the details of construction, and to improve his general knowledge of mechanical engineering.

Subsequently Mr. Goddard entered the employment of Messrs. Maudslay and Field, the eminent marine engineers, where speedily his superior intelligence and industry became conspicuous, and he was chosen to fit up some extensive machinery which was in the course of construction for the Turkish Government for the Mint at Constantinople. It was also intended that he should have the management of the machinery when in active operation, and for this purpose he had permission to make himself personally acquainted with all the proceedings at the Royal Mint, London, and necessarily he was allowed free entry to all the various departments of that establishment. Here he was much indebted for practical informa-

tion to Mr. Joseph Newton, Assoc. M. Inst. C.E., who had recently been appointed Engineer at Tower Hill. However, owing to a change in Turkish politics, the order was countermanded, and the arrangement with Mr. Goddard came to nothing.

Ebenezer Goddard's father had been connected with the Ipswich Gas Company, as one of the committee of management, as early as 1826, and eventually became Secretary and Engineer of the Ipswich Company, which positions he held for several years, but failing in health, in 1842 his son was summoned home to assist him in the business.

In the month of November of that year, the father died and his son was appointed his successor, for which office his general education, as well as his practical knowledge as a mechanical engineer, admirably served him, and as events afterwards proved, these great acquisitions were seconded by sound commercial ability; hence on reference to the earliest published statements of 1851, respecting the positions of gas companies in general, it appears that the Ipswich Company paid a dividend of 7½ per cent., whilst nineteen out of twenty paid no dividend whatever, and many were actually losing concerns.

Having adopted gas-lighting as his specialty, Mr. Goddard introduced at various times several improvements in that art. He was the first to propose the system of letting gas cooking-stoves on hire to the consumers at a moderate rental, which system was practically adopted at Ipswich in 1851. This system is now becoming generally entertained by gas companies with considerable advantage, as their business is by these means continued during the daytime as well as at night, without any augmentation of capital. At the early date mentioned, Mr. Goddard manufactured gas cooking-stoves of such excellence that they would favourably bear comparison with the best descriptions of the present day; and to him is due the merit of first applying fibrous asbestos to gas heating-stoves, in order to present the bright cheerful appearance so much desired. He was always prominent in the introduction of any improvement, and he was among the earliest manufacturers of sulphate of ammonia, which has now become so important a subject in connection with gas industry.

It may be briefly stated that his connection with the Ipswich Gas Company was of the most successful character, as during the forty years it was managed by him the undertaking was among the most prosperous concerns of the kind. The price charged for gas in 1842 was 12*s.* 6*d.* per 1,000 feet, from which it was reduced on various occasions, and for some time past it has been about 3*s.*

Being of an active and energetic nature, in addition to the position he held with the gas company, Mr. Goddard became a ship-owner, and subsequently was Chairman of the Ipswich Maritime Association; he was also Deputy Chairman of the Gas-Purification Company, and was connected with other companies, and in such esteem was he held in his native town, Ipswich, where he passed the greater part of his life, that he was thrice elected Mayor; he was also an Alderman and Justice of the Peace.

In the height of his prosperity he always had in view the welfare of those under his orders, and the working-class generally, and frequently with the object of elevating their minds, and inculcating the necessity for sobriety and industry, he delivered lectures at the Ipswich Mechanics' Institute, and with considerable success. Mr. Goddard was one of the most prominent and highly-respected members of the gas interest; his fine open countenance, his ever courteous manner and affable nature, commanded the regard of all. In 1869 he was chosen the third President of the Gas-Managers' Association (now the Gas Institute), and in his inaugural address gave a highly interesting account of the discoveries and manufacture of coal-tar dyes. For some time past he had been suffering from a disease of the heart which confined him to the house during the winter months, but lately the disease assumed a more serious aspect, and he died, esteemed by all who knew him, on the 19th of October, 1882.

He was elected an Associate of the Institution on the 5th of March, 1850, and on several occasions took part in the discussions at its meetings.

MR. EDWARD HEDLEY, son of the late Mr. Edward Hedley, mining engineer of Wigan and Bristol, was born at the former place on the 9th December, 1836, and commenced his career as a mining engineer under the late Mr. P. Reid, at Pelton, near Chester-le-Street. After serving his articles he removed to Barnsley, where for four years he acted as chief assistant to Mr. John Brown. He was then for some time in the office of the late Mr. T. Tolson White, of Wakefield, mineral agent, after which he removed to Derby, where he resided to the time of his death. At Barnsley he was connected with the Oaks, Strafford-Darley, Main, Stanley, Lund Hill, and other collieries, and took an active part in the explorations following the explosion at the last-named place.

In the Midland counties he had an extensive practice, and had been connected, either as manager or consulting engineer, with the following collieries, among others, Annesley, Rother Vale, Granville, Bagworth, Nailstone.

For the two years before his death Mr. Hedley had been suffering in health, and finally succumbed on the 11th September, 1882. He was elected a Member of the Institution on the 2nd of February, 1875.

MR. SAMUEL FURNESS HOLMES was born at Eyam, in Derbyshire, in 1821. As a youth he was apprenticed to Messrs. Moulson Brothers, edge-tool manufacturers, of Sheffield. Here, a few years later, he commenced practice as a surveyor, and was appointed Surveyor for the Ecclesall highways. In 1864 he became Borough Surveyor, an appointment which he held till 1873, and was then elected Consulting Borough Surveyor. In 1875 Mr. Holmes resigned the office, and ceased to have any further connection with the Corporation. Professionally he was in repute for the care and accuracy of his valuations. When the Midland Railway Company constructed their main line from Sheffield to Chesterfield, he acted as their valuer, negotiating for and purchasing the necessary properties; and subsequently, in his arrangements on behalf of the Corporation, the thoroughness with which they were completed gave the utmost satisfaction to the Committee of the Corporation. He died on the 12th of July, 1882, the primary cause of his death having been an accident in 1870, which gave rise to abscess on the pleura. Mr. Holmes was elected an Associate of the Institution on the 23rd of May, 1865.

MR. LOUIS AUGUSTE DE JACQUES DE LABASTIDE was born in Port of Spain, Trinidad, on the 23rd of November, 1846, at which place his education was commenced under a private tutor. In 1860 he was sent to Paris, and placed in the Lycée Louis le Grand, where he remained six years. In 1866 he obtained at the University the degree of "Bachelier ès Sciences." He then entered the Lycée St. Louis, to study the higher mathematics. Here he carried off the prize, and was admitted a member of the Special Mathematical Society in that University, and was subsequently admitted to the "Ecole Centrale des Arts et Manufactures."

In June 1869 he returned to Trinidad, and entered the Public

Works Department as draughtsman. When occupying that position he was elected an Associate of the Institution, on the 14th of April, 1874. On the 1st of June, 1879, he was removed to the Surveyor's Department, and had commenced the topographical survey of the island, when he contracted a fever, of which he died, on the 24th of May, 1882, in Port of Spain.

Mr. THOMAS MILBOURNE MACFARLAINE was the son of the late Mr. Charles Macfarlaine, Coffee Planter, of the Shevaroy Hills, and was born at Salem, in the Madras Presidency, about the year 1840. After receiving his education at the Vepery Grammar School, Madras, he was articled as an engineering apprentice to the Madras Railway Company. Whilst serving in this capacity, he studied the details of his profession under Messrs. Bruce, Heppel, and Beattie, MM. Inst. C.E. On completing his apprenticeship, he obtained an appointment as a Special Assistant Engineer in the Mysore Public Works Department, where he acquired a knowledge of irrigation-works. In March 1868 he was appointed as a District Engineer in H.H. the Nizam's Public Works Department, Hyderabad, Deccan, and was employed for some years in the irrigation-district of Kummum, constructing and repairing tanks, channels, roads, and public buildings, &c. In 1874 he was entrusted with the charge of the Southern Division, which included the districts of the Raichores, Goolburgah, and Shorapore; and in 1876–77 he took an important part in superintending the Famine Relief Works, carried on throughout this division. The zeal displayed by Mr. Macfarlaine during this trying time was acknowledged by the thanks of the Nizam's Government. He was promoted to the rank of Executive Engineer in November 1878. In 1880 Mr. Macfarlaine visited England, and on the 7th of December was elected an Associate Member of the Institution. On his return to India, at the commencement of 1881, he resumed charge of the Southern Division, where he remained until his death, at Goolburgah, on the 7th of October of the same year, from an abscess, supervening on an attack of cholera.

Mr. DOUGLAS D'ARCY WILBERFORCE VEITCH, the youngest son of the Rev. W. D. Veitch, was born in Jerusalem in 1846, where his father at that time was head of a missionary college. He studied with the intention of entering the Royal

Artillery, but was prevented from carrying out this wish by the state of his health, which was so delicate as a child that he could not be sent to school. He attended the Applied Sciences Department of King's College, London, from October 1864 to Christmas 1866; and in the month of May 1867 became a pupil, for three years, of Mr. W. Clarke, M. Inst. C.E. He was then engaged upon the Whitchurch and Tattenhall Railway, as an Assistant Engineer, during the construction of the works, and afterwards had charge of a section of the Bristol and North Somerset Railway. His health subsequently broke down completely, and he eventually died from long-standing heart disease, at Eliock House, Sanquhar, Dumfriesshire, on the 18th of March, 1883. Mr. Veitch was one of the original Students of the Institution, having been admitted to the class on its formation in November 1867. He was elected an Associate on the 7th of February, 1871, and became an Associate Member on the establishment of that class.

MR. RALPH FIRBANK was born on the 22nd of July, 1837, at Toft Hill, a small village in the centre of the Durham coal district. At the age of seventeen he entered the services of his uncle, Mr. Joseph Firbank, then coming into notice as a contractor who had risen, by his own exertions, from the humblest ranks of railway workmen. For the next seven years he was employed in various subordinate positions in connection with engineering works, in converting tramways into railways, and in the construction of new canals, railways, railway stations, carriage, wagon, and engine shops, the principal of these being the widening of the London and North Western Railway from Willesden to Tring, and the Shoreham and Horsham branch of the London, Brighton and South Coast Railway. During this time, by dint of hard work, perseverance, and constant study, he qualified himself for the position of engineer; and in 1861 he went on to the Bedford and Cambridge Railway as contractor's engineer. There he had charge of the construction of a length of 12 miles at the Cambridge end of the line, including the building of the stations, goods-sheds, and engine-sheds at the terminus.

In March, 1863, he took charge of the works of the South London Railway between Brixton and Bermondsey, on behalf of Mr. Joseph Firbank, designing the temporary bridges and appliances for carrying out the works, which consisted of bridges, heavy retaining-walls, viaducts, and covered ways of great width

and depth in the London Clay. From January 1865 to July 1869 he was engaged on the Midland Railway extension to London between Kentish Town and Radlett, having sole charge on behalf of the contractor. The works included the Belsize tunnel, 1 mile long, in the London Clay, several other short tunnels and covered ways, a large viaduct over the River Brent, and many bridges, culverts, and sewers. He designed all the various appliances for the construction of the tunnel, such as the winding-gear, and the temporary constructions required for carrying out the work quickly, besides completing the line, and reconstructing several bridges on the Midland and South Western Junction Railway between the River Brent and Acton station. From July 1860 to May 1877 he was manager and engineer, on behalf of Mr. Joseph Firbank, the contractor for numerous branches and extensions of the Great Northern Railway. These comprised the Wood Green and Enfield branch, the Sleaford and Bourn Railway; widening the line from Wakefield to Ossett, and the new Ossett and Dewsbury Railway; the branch line from Finsbury Park to Canonbury, connecting the Great Northern and North London Railway systems, including a tunnel 600 yards long, in the London Clay, and a skew bridge, about 100 yards long, under the main lines; the Erewash Valley Extension; that portion of the Derbyshire and North Staffordshire Extensions, between Derby and Burton-on-Trent; the New Copenhagen tunnel and widening-works, and the new tunnel at Maiden Lane, King's Cross, with bridge and covered way under the Regents Canal.

In May, 1877, he commenced what promised to be a most successful career as a contractor on his own account, entering into partnership with Mr. C. Baker, of Barlborough, Mr. Firbank being the managing partner. The following works were carried out by the firm:—the Batley and Dewsbury Railway, a short line in the manufacturing district of Yorkshire, on which the works were exceptionally heavy. Two new bridges over the Bradford canal, and new roads for the Windhill Local Board; a tunnel under the River Aire, at Kirkstall, for the Leeds sewage scheme. In this case the sudden rising of the river washed the cofferdams, &c., away no less than four times. Widening the Manchester and Liverpool line of the London and North-Western Railway from Manchester to Barton Moss, the embankment for which extends over a portion of Chat Moss. And, finally, the northern section of the Great Northern and Great Eastern Railways joint extension lines from Spalding to Lincoln. The works on this line are the heaviest yet executed in Lincolnshire, two of the largest cuttings

containing more than 1,000,000 cubic yards of excavation, principally limestone. The amount of the contract was about £250,000, and the whole of the work was brought to a successful termination within two years of the commencement.

In 1881 Mr. Firbank undertook the construction of the Grahamstown and Port Alfred Railway, South Africa, a line connecting the capital of the eastern province of Cape Colony with the new port at the mouth of the river Kowie, and now approaching completion. At the time of his death he was contemplating a visit to the Colony in connection with this and other proposed railways.

Mr. Firbank was an admirable representative of the fearless, bluff, honest, and hearty type of the go-ahead English contractor. Thoroughness was always a first consideration with him, and few men have given more thought or care to their work than he did. His desire always was that whatever he undertook should be done in the best possible manner; and his favourite maxim was, that if a thing was worth doing at all, it was worth doing well. As an employer of labour he will ever be remembered with regard, and even affection, by his workmen, especially the navvies, as he took the greatest interest in their welfare. On all his works he provided them with reading-, coffee-, and mission-rooms, and his active assistance, both personal and pecuniary, could always be counted on in any scheme for their entertainment or instruction. On Friday the 15th of December, 1882, he left London to return to his home at Washingborough, near Lincoln; he was seized with an apoplectic fit on the following Sunday evening, and died on Tuesday, the 19th of December, at the early age of forty-six.

Mr. Firbank was elected an Associate of the Institution on the 4th of March, 1879.

LIEUTENANT-COLONEL WILLIAM ROBERT JOHNSON, M.S.C., was born on the 17th of July, 1830. He received his engineering education at Putney College, obtained a commission as ensign in the army of the H.E.I.C. on the 20th of December, 1849, and was appointed to the 15th Regiment N.I., on the 4th of February, 1850. He was not long in attracting the attention of General Budd, after, which, having got into the Public Works Department, under Captain (now Lieutenant-General) Walker, R.E., in Bellary, he was one of those selected in 1857 for the newly formed Public Works Department in Mysore. From that time he steadily rose in rank, till, on the 1st of January, 1880, he was

named definitely head of the department, as First Class permanent Superintending Engineer, a position which he held till his death. As Executive Engineer in the Ashtagram Division, he carried out a large number of most useful works, and while so engaged studied the requirements of the ancient system of native irrigation-channels, and gained a knowledge which, on his being made Superintending Engineer for Irrigation, he turned to the best account. The great and lasting improvements which he was enabled to effect in these extensive works, are such as should never be forgotten by the people of Mysore. The maintenance of the thirty-eight thousand tanks in that province engaged his attention for the last ten years of his life; and it is not too much to say that, chiefly through his exertions, the principles of management of these works, which are of vital importance to Southern India, were placed on a firm basis. The largest work which, as an executive officer, he carried out, was the completion of the bridge over the Toonga Bhadra river at Hurryhurh. Assuming charge of the bridge after the death from cholera of the contractor, Mr. Cockburn, he in three months turned and uncentred no less than ten elliptical arches of 60-feet span each. Possessed of great physical powers, a pugilist of no mean pretensions, a leader in all athletic sports, and wherever good fellowship was to be found, his cheery laugh and keen brusque wit will long be remembered. But beyond all this, there was an amount of keen sagacity, straightforward honesty of purpose and genuine kindness, all of which were turned to the best account in the interests of Mysore. He was elected an Associate of the Institution on the 4th of February, 1868, while on a visit to Europe. He died in London, of gout, on the 7th of June, 1882.

Mr. JAMES SHAW was born in Aberdeen, of humble parentage, on the 27th of August, 1836. He received in his boyhood a scanty education; but previous to his apprenticeship in his native city to the late Mr. Jonathan Mess, miller, he appears to have been for a short period at Mr. Ledingham's academy, in Correction Wynd, and held a high place in the esteem of his teacher for his plodding and persevering qualities, being singled out and spoken of to the school as "one of the shining lights of the future."

When quite young James Shaw gave evidence of considerable talent and business ability. He was poor but ambitious, and his

subsequent successful career justified the allusion to his departure from the city made by himself on the first occasion on which he sought its suffrages.

"I have no doubt (he said) a good few will ask the question, Who is James Shaw? I have the profoundest pride in answering that question. I left this city twenty years ago, at fifteen years of age, a poor, penniless, friendless Aberdeen lad. There is not a man in this assemblage, however poor, who has not at this moment greater advantages than I had when I quitted my native city. I don't think I had more than the price of a railway ticket to Edinburgh; but I left it with hope; I left it, I trust, with some degree of principle; I left, at all events, with some native Aberdonian energy, and I return to you, gentlemen, twenty years afterwards, to offer myself to you as your representative in Parliament."

At the age of sixteen he obtained a situation as junior clerk, in the Glasgow office of the then well-known firm of metal brokers, Messrs. Short & Co., of London and Glasgow. Young Shaw's intelligence and high business qualities were quickly perceived by his employers, and he was, a few years later, removed to the London office, where he remained until he was twenty-one years of age, when the Glasgow branch of Messrs. Short and Co.'s business was presented to him. Always anxious to improve his position, he, during his stay in London, attended evening-classes, and in this way made up for the deficiencies of his early education.

On commencing business on his own account in Glasgow, in 1857, he took into partnership Mr. James Thomson, who had previously been engaged in the dry goods trade, and founded the firm of Shaw and Thomson, which afterwards became one of the most important in the iron trade. Mr. Henry Moore was some years later admitted into the firm, and the business was carried on under the style of Shaw, Thomson, and Moore, until August 1865, when this partnership was dissolved, and the firm of Shaw and Thomson continued, the business having been removed from Glasgow to Leadenhall Street, London.

In 1870 Mr. Thomson died, and the business devolved upon Mr. Shaw. The firm of Shaw and Thomson conducted an extensive foreign trade, and supplied the ironwork for the Athens and Piræus Railway (the first railway constructed in Greece), at the opening of which H.R.H. the Prince of Wales was present; and Mr. Shaw had the honour of conducting His Royal Highness over the works, and received from the Prince, upon his return to England, a scarf-pin as a memento of the occasion. Messrs. Shaw and Thomson constructed the Ghizeh Bridge across the Nile at Cairo, when Mr.

Shaw, who was personally well known to the then Khedive, Ismail Pasha, was presented by His Highness with his autograph portrait. Mr. Shaw also supplied the iron permanent-way for the construction of 150 miles of railway in Egypt, besides numerous other undertakings, and also obtained the stores-contract from the Egyptain Government. The firm supplied many thousands of tons of iron permanent-way to the Indian, Australian, New Zealand, Belgian, Italian, and other governments, and carried out some other extensive contracts. In the years 1871–2–3 Mr. Shaw realized a large sum of money, and was unquestionably a rich man when he was elected to serve the office of Sheriff of London and Middlesex for the year 1874–5, and during his Shrievalty visited the French capital, in state, together with the then Lord Mayor of London and his co-Sheriff (now Sir John Whitaker Ellis, Bart), but towards the latter part of his year of office in 1875, a year so terribly disastrous to the iron trade, his financial position became greatly altered, and, under the circumstances, he decided to abstain from the duties of the office of Sheriff for the short remaining period then wanting for the due completion of its tenure, never having resigned the office, as has been erroneously stated.

In May 1877, the well-known and extensive establishment of the Governor and Company of Copper Miners in England, better known as the Cwm Avon Ironworks, were disposed of to Mr. James Shaw and some associates. This famous company was incorporated by Royal Charter in 1691, and went into liquidation in July, 1876, having succumbed to the storm which wrecked so many other concerns engaged in the iron-trade. It is well known that their great works had cost this ancient Corporation over a million and a quarter of money. Mr. Shaw worked this property for some years with remarkable success, and at a later date, formed the property into a limited liability company, which has since gone into liquidation. During his stay at Cwm Avon, the employees presented to Mr. Shaw a marble bust of himself as a token of the great esteem felt for him by those connected with the works under his proprietorship.

Mr. Shaw thrice contested the representation of his native city in Parliament, in the Conservative interest, viz., in 1872, 1874, and 1880, on each occasion, however, unsuccessfully. In 1874 he was absent in Egypt, and telegraphed two addresses to the electors, and the increasing numbers of his supporters was proof of his growing popularity. He was an attractive and fluent speaker, and the pluck and good humour he exhibited in repeatedly fighting losing battles earned for him a good deal of general

public admiration. He was the author of a series of papers entitled "Sketches in the House of Commons, Personal and Political," published in 1871, under the name of "A Silent Member," which attracted considerable attention. He was also a frequent and able writer in metropolitan and other papers, and was always a welcome contributor. The generosity of his character was most marked, and to many a struggling lad he proved a most valuable friend, finding for them situations and otherwise aiding them. He was a member of the Merchant Taylors' Company, a Past-Master of the Farriers' Company, a member of the Loriners' Company, a Justice of the Peace for the County of Glamorganshire, and was elected an Associate of the Institution of Civil Engineers on the 3rd of March, 1868.

Mr. Shaw was connected with the town of Stockton-on-Tees, so far as he was a partner in the firm of Shaw, Johnson, and Reay, of the Moor Iron Works; from that firm, however, he retired some years ago. The anxiety incident to the fluctuating character of the iron-trade had of late years seriously affected his health, which had always been of a delicate nature, and a constant cause of carefulness and consideration from his boyhood; and it is probable that this cause accelerated his death, which occurred on the 23rd of May, 1883.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Periodical Movements of the Ground as indicated by Spirit-levels. By P. PLANTAMOUR.

(Archives des Sciences Physiques et Naturelles, Geneva, 1882, p. 551.)

The two spirit-levels, before described,[1] have been regularly observed for a fourth year, viz., to the 30th September, 1882, and a comparison is here made of their curve-traces with those of former years.

I. *The Level placed East and West.*—The curves described by the east end during the first, third, and fourth years are strikingly similar, more especially those of the first and fourth years. The subjoined Table shows this at a glance :—

Year.	Depression of East End.	Rise of East End.
1878–1879	17·61 seconds	28·08 seconds
1879–1880	95·80	21·48
1880–1881	36·41	21·48
1881–1882	18·42	21·43

The small rise in this last year is probably due to the relatively low temperature of the summer of 1882; but in spite of this the rise has exceeded the winter's fall by 3 seconds, this being the first time this has occurred since 1878–79, when, consequent on a hot summer, it was 10·47 seconds in excess. In the two intermediate years the fall largely preponderated.

Again, since the severe winter of 1879–80, when the east end was exceptionally low, its annual rise is identical for the three years 1879–82. This is probably due in part to the relatively low temperature of the three last summers. It is hard to account for the great differences that exist between the dates of the maximum rises and falls of the east end as compared with the temperature, particularly as regards this fourth year, while in 1881 the maximum elevation of this end preceded that of the temperature by four days. Very probably the degree of moisture or drought in the ground exercises a perceptible influence on the

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[1] Minutes of Proceedings Inst. C.E., vol. liv., p. 286; vol. lx., p. 412; vol. lxiv., p. 343; vol. lxviii., p. 321.

rapidity with which the temperature acts through greater or less depths of soil. For instance, the summer of 1882 was very wet, especially from the 15th August to the end of September, and the east end has risen since June, gradually and without check, to the 30th of September, and has even continued to rise in October, which it never did previously.

II. *The Level placed in the Meridian.*—The amplitude of the oscillation of the south end has been 7·13 seconds, which is 3·07 seconds less than that of the preceding year, though greater than those of the two first years by 2·24 and 2·57 seconds. The curve-trace for all the four years is strikingly alike, even to showing the same peculiarity—as regards the secondary ground movements—of acting in a contrary direction to the temperature, the cause for which is not yet apparent.

The Author concludes by regretting that, with the exception of Colonel von Orff and Mr. d'Abbadie, no one has instituted similar continuous observations of spirit-levels.

Colonel C. von Orff, in a letter to Mr. Plantamour, sends the results of a second year's observations at Bogenhausen. His spirit-levels, Nos. 1 and 3, placed in the meridian, again give different readings, and, on closer examination, these differences are traceable in part to the dissimilar conditions of their setting-up. In order to check the readings of spirit-level No. 1, Colonel von Orff made another level, No. 4, which he set up alongside No. 1, and on the very same support. The readings however, contrary to his expectation, widely differed, and on investigation it was found that the cement used for fixing its bubble-tube was so damp that no stability for the latter could be expected. Colonel von Orff has come to the conclusion that wax is the best material for guaranteeing the necessary immobility to bubble-tubes employed on these observations, but intends making further researches on the subject.

Spirit-levels Nos. 1 and 3 both show a periodic movement, while No. 2, placed in the direction west-east, does not do this, although its indications accord generally this second year with those of the level of the meridian instrument.

Colonel von Orff reasserts that these level-observations are not fitted to disclose changes in the position of the vertical (as supposed by Mr. d'Abbadie), because the supports of the spirit-levels are proved to be deficient in absolute immobility. Neither are they due solely to the direct effects of variations of temperature producing expansion and contraction in the different layers of earth. They are, he thinks, caused by a slight undulation in the layers forming the earth's surface, since these layers possess different degrees of cohesion, and this is sensibly modified by their different degrees of humidity.

E. H. C.

Rapid Methods in Topographical Surveying.

By Wm. Bell Dawson, Assoc. M. Inst. C.E.

(Transactions of American Society of Civil Engineers, Nov. 1882, p. 397.)

A map of the gold-field on the Atlantic coast of Nova Scotia having to be prepared on a scale of 2 inches to the mile, as well as three special plans on a scale of $\frac{1}{6000}$, and this district being far too intricate for survey with the chain, the Author employed instead "stadia" measurements and the Rochon micrometer-telescope. The traverse lines ran along the roads and principal streams, forming a network of quadrilaterals, and were plotted by the method of co-ordinates. The instruments used were a Sopwith levelling-staff, and a 6-inch theodolite with a vertical circle and $4\frac{1}{2}$-inch compass-needle; the theodolite was fitted with three horizontal spider-lines, unequally spaced, the larger interval corresponding to 100 feet of distance for each foot intercepted on the staff: the smaller one was only used for longer sights and when the view was obstructed.

The angular values of the spaces between the hairs were found by direct measurement, and Tables were thence calculated.

The Rochon micrometer-telescope was a double-refracting one, with a vernier reading to seconds, and a range of from 0 to 45 minutes: it was used with a pair of disks set 8 feet apart, its accuracy having been first carefully tested, in order to obtain the index-error of the instrument. By these methods the Author found that with one assistant and one or two men, according to circumstances, he could carry on all the survey-work.

The theodolite and staff were used in traversing, being moved forward alternately, and the same end of the needle read throughout the work: sights of 200 to 400 feet gave the quickest work, the rate of advance, without levels or intermediate sights, being a mile an hour; but in road-work 3 to 4 miles per day, including levels. The great advantage of stadia-measurements over chainage was most apparent when sighting across the ponds and swamps met with on streams. On traverses of secondary importance a prismatic compass and ranging-rod were used, the distances being taped: this plan was found expeditious in the denser thickets. In surveying the larger lakes, the theodolite was set up at a commanding spot, and the micrometer-telescope beside it in a trough-shaped support on a tripod. The assistant went round the edge of the lake in a boat, holding the staff with the disks vertically at all important points, and finally giving a turning-point, where he remained while the boat returned to remove the instruments to their next station. Here a back-sight was taken on the turning-point, and the work carried on as before. Forms of the note-books kept in "stadia" work and in levelling are appended.

Sights with the micrometer-telescope ranged from 600 to 5,000 feet, though limited for the most part to 1,000 and 2,500 feet,

because 5 seconds of angular value (the smallest division which could generally be read with facility) give an error of 3 feet at 1,000, and of 18 feet at 2,500 feet distances. Distances found with the micrometer-telescope generally exceeded those obtained by stadia-measurements. One great advantage of this telescope was, that whenever landing at any intermediate point was difficult, the staff could still be held on the edge of the boat, as the slight vertical motion due to the waves in no way marred the observation. Of course some light was lost in passing through the double refracting prism, and this was inconvenient on dull days. Also, on short sights, the obliquity of the light from the two disks made the images indistinct; but, as compared with the length of the sight, an angular difference here was of less moment. For work of this varied character the Author considers an ordinary 4- or 5-inch theodolite—adapted for stadia-measurements—the most suitable instrument; illumination for the cross-hairs and a diagonal eye-piece are desirable, as also a separate telescope, either double-refracting or with a divided object-glass for the measurement of longer distances, and it should be capable of being rotated axially. The rod should be 10 or 12 feet long, and hinged in the middle, the two faces folding together for protection, with the disks attached to the back.

In five months of field-work an area of 180 square miles was surveyed, including nearly one hundred lakes, from 7 miles long downwards: wet days were devoted to the reduction of all the observations. The traverses generally closed within an area of 20 to 30 feet radius on the ground, but by the numerous independent checks taken, any errors were almost entirely eliminated in the plotting. The total cost of the survey was $16¾ (say £3 11*s.* 6*d.*) per square mile.

E. H. C.

Experiments on the Elasticity and Strength of various Materials.

By J. Bauschinger.

(Der Civilingenieur, 1882, p. 561.)

This is an account of a number of tests (thirty-nine in all) made upon various materials and forms with the Werder Testing-Machine, in the presence of an assembly of technical men invited for the purpose of witnessing the experiments at the exhibition in Nuremberg (Landes-Ausstellung), the measurements being carried out by means of instruments designed by the Author.

The results are given *in extenso* in the Paper.

The materials comprised wrought and cast iron, steel, leather, wood, sandstone, and granite, and were tested for their resistance, deflection, &c., as regards tension, compression, buckling, transverse loads, torsion and shearing.

The following general results, which these experiments tend to confirm, deserve notice:—In the case of transverse loads on wrought-iron or steel the modulus of elasticity—as calculated by the ordinary formula—is decidedly smaller than for tension or compression, the transverse strength of the lower part of a beam or girder is however greater than the tensile strength would indicate, and in the upper portion less than would correspond to the compressive strength.

The formula of Laissle and Schübler for the strength of cast-iron columns,

$$P_o = \beta_o F \frac{1}{1 + \kappa \frac{F}{\Theta} l^2},$$

where P_o is the breaking-load, F the sectional area of the column, Θ the moment of inertia, l the length, β_o the crushing-stress per unit of area of a cube of the same material, and κ an experimental coefficient, was found to give accurate results with the value assigned to κ by these authorities, provided the material was perfectly sound and the coring (of the hollow columns) central, when however these conditions were not fulfilled, as is frequently the case (especially with long columns cast horizontally), the value of κ proved by experiment to be much greater; under the first-named conditions $\kappa = 0 \cdot 00022$ (which is the value given by Laissle and Schübler), while in the latter instance $\kappa = 0 \cdot 0006$.

All the experiments with cast-iron test-pieces, both on crushing, buckling, and torsional resistance, tend to prove that it possesses no limit of elasticity, and that the modulus of elasticity, calculated by the usual formula, decreases continuously with an increase of the load.

The tests on the tensile resistance of bar-iron confirm the observations of previous investigators that the strength of the test-pieces is not diminished by repeated stress but rather increased, while the modulus of elasticity and contraction are diminished.

These experiments have a special interest as they were made upon pieces of considerable size. The largest column had a diameter of 13·43 centimetres (5·29 inches), and a length of 361·5 centimetres (11 feet 10·32 inches), while a portion of a girder having a depth of 30 centimetres, or nearly 12 inches, was tested for transverse strength, the supports being 250 centimetres (8 feet 2·42 inches) apart.

G. R. B.

Technological Studies on Materials and their Alterations of Form. By Friedrich Kick.

(Technische Blätter, 1882, p. 215.)

In this Paper the Author deals with the results of experiments made with the object of determining the relative quantities of energy required to fracture by impact bodies of similar form but different sizes. He had previously established the law with regard to the deformation of plastic materials that "the quantities of work necessary to produce similar deformation in geometrically similar bodies, have to each other the ratio of the volumes or weights of those bodies," and wished to ascertain whether the same law applied to the case under consideration. Hitherto, he states, it has generally been assumed as self-evident that the work required for breaking, crushing, stamping and grinding, is proportional to the area of the fractured surfaces; the experiments referred to showed this not to be the case, while the results agreed very fairly with the Author's law. This is expressed mathematically by the formula A to $A_1 = 1 : a^3$, where A and A_1 represent the work required to fracture respectively two pieces, the ratio of whose analogous dimensions is a.

The bodies tested were spheres, cubes, and cylinders of stone, cast iron, glass and marble; the fracture was produced by a falling monkey, the height of fall being gradually increased until just sufficient to produce rupture in one piece of a given size, the others of identical dimensions were then broken at once by a fall from this height. The most important experiments, and those of which the fullest particulars are given, were made with cast-iron spheres, varying in diameter from 115 to 12·7 millimetres (4·528 inches to 0·5 inch); the extreme effective weights of the monkey used were 473 and 0·555 kilograms (1040·6 and 1·22 lbs. respectively), while the height of fall ranged from 2·32 to 0·32 metres (7 feet 7·3 inches to 1 foot 0·6 inch).

Between very wide limits, the accuracy of the laws was not affected by the velocity of the fall, the effect being the same whether the latter were high or low, provided the energy were maintained constant by proportionately altering the weight.

The majority of the spheres split into three approximately equal parts, the surfaces of fracture radiating from a central axis; the same phenomenon showed itself with cubes, while the cylinders (of glass) broke transversely in the usual way; the law abovestated appeared, however, to apply equally well to all the substances tested.

The Author introduces into his calculations what he terms the "factor of rupture," which represents that amount of work required to fracture a piece of the weight of 1 kilogram; this will, for any piece of similar form and a given weight, when multiplied by the latter, give the work requisite to fracture it.

The principal results of the experiments are given in a tabular form.

G. R. B.

[NOTE.—It has been proved theoretically in a very simple manner that the law stated by the Author must apply in the case of test-bars of any section crushed by a falling weight (or other force) acting on one end, and also in that of bars of rectangular or circular section supported at both ends and broken transversely. For crushing the proof is as follows (it is similar for transverse fracture); Let P be the crushing-load which would correspond to the compression δ at the moment of rupture in the test-piece, and cause the crushing-stress s per unit of sectional area, then, by well-known laws, the work corresponding to the deflection δ is $W = P\frac{\delta}{2}$—assuming the limit of elasticity to be coincident with rupture—also $P = F s$, where F is the sectional area of the test-piece, and $\delta = C\frac{P l}{F}$, l being the length of the piece, and C a coefficient comprising all the constants depending on the section and material; then substituting and simplifying $W = \frac{1}{2} C F l s^2$.

Now $F l$ is the volume (cubic contents) of the piece, hence

$$W = C \tfrac{1}{2} s^2 V,$$

and this is independent of geometrical similarity in dimensions.—G. R. B.]

On the Permanent and Elastic Alterations of Form in Raw Silk. By ERNST MÜLLER, Dresden.

(Der Civilingenieur, 1882, p. 361.)

The interesting phenomena occurring in the case of metals on repeated applications of stress, led the Author to extend similar investigations to *animal substances*, and for this purpose raw silk was in the first instance chosen, on account of its strength and elasticity. The experiments, which were carried on in the mechanical-technological laboratory of the Munich Polytechnic, had reference to the tensile resistance and elongation of the material. The form of the cross-sections was microscopically determined, and proved to be approximately elliptical, the major and minor axes being respectively 0·0134 and 0·0127 inch in diameter.

The free lengths of the test-pieces varied from about 10 to 12 inches.

The tests showed that, as in the case of metals, the limit of elasticity is raised by repeated intermittent stresses, some time being allowed to elapse between the applications of the loads. The results are given in a tabulated form and illustrated by diagrams.

G. R. B.

On the Pressure of and Motion in Masses of Dry Sand.

By Privatdocent P. FORCHHEIMER, Aachen.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, vol. xxxiv., 1822, p. 111.)

In this article the Author describes experiments made by him with the object of determining the pressure exerted by dry sand on retaining surfaces under various conditions, and the motion and form taken by it when collapse occurs. He also investigates the phenomena theoretically, making the simplifications of his general formulas justified by the experimental results. The first series of experiments undertaken aimed at ascertaining the pressure exerted on the bottom of a vessel in which sand is piled up to various heights, and the form assumed by it on collapse.

The apparatus used consisted of a wooden hopper having the shape of a truncated pyramid, in the bottom of which—the smaller end being downwards—apertures of different shapes and sizes could be inserted, these being closed by a round, flat plate, on which the pressure of the sand was exerted, and attached to the end of a scale-beam, by means of which equilibrium could be maintained, this served to measure the pressure. The diameter of the circular apertures used varied from 20 to 2·12 centimetres (7·87 inches to 0·83 inch).

For observing the alterations of form produced by collapse the aperture in the base of the hopper was furnished with a short tube into which fitted a stopper capable of being raised or lowered. To obtain a record of the deformation taking place in the interior, when the sand was allowed to subside by the stopper being lowered, the former was arranged in the hopper in alternate coloured and uncoloured layers, and when deformation had occurred, permeated by melted paraffin, which, on cooling, cemented the whole mass together in a solid body admitting of being sawn through, thus showing in section the nature of the alterations in form. These experiments proved that in the case of a circular aperture, on lowering the supporting stopper, a vertical cylinder of sand having as basis the aperture itself, was set in motion; the subsidence in the various sand layers decreasing towards the upper surface, in the case of a slight subsidence, the uppermost strata remaining undisturbed. The effects were similar in the case of rectangular apertures. The colouring matter used was Fuchsin. With the assistance of the results experimentally obtained, the Author develops a formula for the pressure exerted on a given area by a superimposed mass of sand. This pressure, when the height to which the sand is piled exceeds a certain dimension at which collapse occurs, is independent of that height, and for a given kind of sand is a function only of the area and circumference of the subsiding basis, in other words, of the aperture. The calculated and experimental results show a very close agreement.

Further investigations were undertaken with an inclined orifice in the bottom of the hopper. Another series of experiments was carried out to ascertain the nature of the slip-surface where the lateral support of a mass of sand gives way, the conditions obtaining in the case of retaining-walls under various circumstances being imitated as far as practicable. The apparatus used was analogous to that already described, with the modifications necessary for recording lateral instead of a vertical pressure and collapse. The results observed show that with a retaining-wall, the inner surface of which is vertical or inclined outwards, a horizontal or upward displacement of the latter, or a turning motion about the inner edge of the base, is followed by the formation of a slip surface in the sand having an inclination with the horizon of $\frac{\phi + 90^\circ}{2}$, where the surface of the sand is level; ϕ represents the natural angle of repose of the material used. This agrees with the conclusions of many previous investigators of the same problem.

The Author also experimented on the effect produced by a process the converse of the preceding, where sand is displaced by the pressure of the retaining-surface and forced backwards. In this case he found that with a horizontal upper surface and vertical wall, when the mass of sand behind the latter was practically unlimited, a plane slip surface, having the inclination of the natural angle of repose, is formed, which does not pass through the base of the wall; where the mass is limited, this surface becomes steeper the nearer the posterior enclosing wall is to the anterior.

Various other investigations of a less exhaustive character are described by the Author. The materials used were chiefly Rhine-sand, another species of fine sand (*Goldstreusand*) and dust shot. The Author refers to the work of others in the same field, among these are Coulomb, Prony, Winkler, Weyrauch, Rankine, and Baker. The paper is illustrated by diagrams showing sections of the masses of sand after deformation.

G. R. B.

On the Angle of Friction. By Gustav Herrman.

(Zeitschrift des Vereines deutscher Ingenieure, 1883, p. 1.)

When two bodies are in contact the condition that one shall not slide on the other is, that the direction of the line of mutual pressure shall not make with the common normal at the point of contact a greater angle than the angle of friction ρ; in other words, the line of pressure must fall within a cone whose apex is the point of contact, and for which the angle at the apex is equal to 2ρ. The angle of friction ρ is not so much used in practice as

the coefficient of friction ϕ, whereby $\phi = \tan \rho$; but the Author shows in the present Paper how a consideration of the angle and cone of friction may be made to yield interesting results, especially when the graphical treatment is used. The coefficient of friction (ϕ_0) for any two bodies at rest is considerably greater than that (ϕ) for the same bodies when in motion one on the other. The relation between ϕ_0 and ϕ may be easily shown by a simple experiment. If the two hands be held apart, and a rod of any substance be laid across them so as to rest in the forks between the thumbs and forefingers, and if the hands be then gently brought together, it will be found that the rod slides alternately, first over one hand and then over the other, and the hands always meet under the centre of gravity of the rod; by substituting supports of any desired material and using a graduated rod, and noting the exact moment when the motion changes from one support to the other, the ratio $\frac{\phi_0}{\phi}$ can be obtained with great accuracy, and, consequently, ϕ_0 can be determined when ϕ is known. In order to determine ϕ the Author places a body made of the one material on a plane made of the other, the plane is then inclined at any angle α to the horizon, but so that α is much smaller than ρ, a cord attached to the centre O of the body is passed through an eye, K, attached to the plane; on pulling the cord it will be found that the body does not move towards K in the direction O K, but traces a curved path; the Author shows that if O D be the direction of the tangent to the path, O B the direction of the inclination of the plane, and B D be drawn parallel to O K, then

$$\phi = \tan \alpha \frac{\mathrm{O\,D}}{\mathrm{O\,B}},$$

an expression which can easily be determined graphically for any point of the path traced by the body. The Author shows how, in the above case and many similar ones (such as the gradual shaking loose of nuts), although the direction of the force producing contact may lie well within the before-mentioned cone of friction, yet the resultant of this and some other external force may lie on the surface of the cone and cause motion in a direction which is influenced by the first force, although this was not of itself able to produce motion.

The latter part of the Paper treats of the influence of friction on wedges, and explains the reason why a draw cut will sever a material that no amount of direct pressure would divide. The Author also considers, from the same point of view, the crushing action of grinding-rolls, and is led by his reasoning to propose a wedge-and-roller mechanism, by which great pressure may be produced with a very slight amount of friction.

W. P.

Sand-box for Lowering the Centres of Arches. By J. Smith.

(Professional Papers on Indian Engineering, October 1882, p. 37.)

For striking the centres of a four-span bridge over the Tamal River, in the Midnapore district, there was required for holding the sand an entirely closed receptacle which would gradually collapse as the weight came upon it, bags, open cylindrical or rectangular boxes, being unsuitable under the conditions. After considerable thought, it struck the Author that empty kerosene-oil tins would answer the purpose, and if so, hardly anything could be cheaper, as they only cost one anna per tin.

The weight which the tins filled with sand would sustain without collapsing having been ascertained by experiment, a sufficient number were placed on the top of masonry pillars and were inclosed by masonry in mud-mortar, so as to prevent their being tampered with. This was also needed as a reserve support in case of a tin bursting through faulty construction. The kerosene-oil tin "sand-boxes" were made to carry the centres by templates and pillar-plates, as usual; and to allow of the immediate collapse on the sand being removed, the templates were made of such a size as to lie within the box. In striking the centres, the casing-bricks were first removed. Coolies, armed with short and sharp-pointed pegs of hard wood and ordinary hand-hammers, were stationed at each box. At a given signal every man struck a hole at the side of his box, and on the pegs being simultaneously removed, and another hole made at the top of the tin, the sand ran out. The lowering, which was very easy and gradual, could be arrested at any point by allowing the sand to accumulate in front of the holes. One side could also be lowered quicker than the other by simply driving another hole into the box and increasing the flow of sand. The maximum weight supported by one of the kerosene-oil tins used was, by calculation, 7·7 tons. No bulging or crushing was perceptible before the sand was run out.

F. G. D.

Repairs to a Road-bridge over the Weisseritz. By A. L. Köhler.

(Jahrbuch des sächsischen Ingenieur- und Architekten-Vereins, vol. i., 1882, p. 165.)

This bridge carries the road leading from Possendorf to Deuben, near Dresden, over the River Weisseritz. The structure, erected in 1877, comprises one skew-arch of an angle of 79°. The normal span is 55 feet 9 inches, and skew-span, 56 feet 9 inches, with a rise of $\frac{1}{10}$, or 5 feet 8 inches. The breadth of the bridge is 23 feet, and the thickness of the arch (of sandstone set in cement-mortar) at the crown is 2 feet $5\frac{1}{2}$ inches, and at the springing

2 feet $9\frac{1}{2}$ inches. The abutments are 19 feet 8 inches thick, of syenite faced with sandstone, set in hydraulic-lime mortar, excepting the courses above the springing line, which are in cement.

The foundations of one abutment rest upon compact clay, and of the other upon the conglomerate. When the arch-centering was struck, the permanent set was $\frac{5}{8}$ inch, and there were no indications of settlement noticed until June 1879, nearly two years after the completion of the work. A fine crack was then observed in the face-stone on the up-stream side of the right abutment, and in the spandrel face-wall above it, followed in the ensuing summer by a fissure which traversed nearly the whole length of the intrados of the arch in the direction of the shorter diagonal, but stopping short at the back of the face-stones (in elevation) of the arch. The width of the crack under the crown of the arch was a full sixteenth of an inch, extending in either direction towards and dying out near the abutments. On investigation, both abutments were found to be out of the perpendicular and to have subsided, the right-hand one especially being $3\frac{3}{4}$ inches lower than the other; the arch also in half its breadth had moved outwards at the springing-course. The settlement proved to have been produced by subsidences in the workings of a 13-feet seam of the Augustus coal-mine, which ran directly below the bridge site, at a depth of 322 yards. The method adopted for repairing was as follows:—The arch was bared, and the course of the crack ascertained; this in most cases followed the joints of the arch-stones, but there were a few stones broken across. As it was probable that the settlement of the abutments would not cease for some considerable time, it was decided to divide the arch longitudinally by two lines of cleavage into three sections, and so distribute among them the effects of settlement. A timber centering was erected to temporarily carry the arch, and the sides of the bridge were bound together transversely by five wrought-iron rods of $1\frac{5}{8}$ inch diameter, with bolts and nuts and washers, to diminish the effects of the vibration produced in the operation of cleavage. Grooves of triangular section, $2\frac{3}{4}$ inches broad and 2 inches deep, were cut, above and below the arch, along the course of each of the intended lines of separation, which were 7 feet $4\frac{1}{2}$ inches from either face of the arch; and steel keys, 4 inches long and 1 inch square, were then driven in the course of these grooves, commencing at the crown of the arch and working towards the abutments. The crack thus created was about $\frac{1}{16}$ inch, and dying out near the abutment, its continuity being tested by the percolation of water poured into the upper groove. The course of the original crack was then cleaned out, the broken stones removed, and the spaces filled with brickwork in cement, and the joints injected with cement; the springing-course being similarly treated. The surface of the bricks was kept a little above the arch-intrados, so as to permit of flushing them with cement, as a protection against frost.

Since the completion of the repairs, although the settlement of the abutments is still proceeding, no further diagonal rifts have

appeared in the arch sections; there is a slight crack in the spandrel wall of the right abutment, but as yet not of sufficient importance to demand repairing.

The cost of the above repairs was £108 15*s*., of which £41 15*s*. was for providing the timber centering.

D. G.

Experiments on the Flow of Water.

By A. Fteley and F. P. Stearns.

(Transactions of the American Society of Civil Engineers, vol. xii., pp. 1–118.)

The Authors first determined a coefficient in a general formula for flow over a weir of the simplest kind, and with the fewest modifying secondary causes. They then proceeded to estimate the effect of secondary causes, such as velocity of approach, side-contraction, width of crest, &c. A nearly constant flow could be obtained from Farm Pond (the surface level of which never varied more than 0·015 foot per hour) through fixed orifices, with a head of about 3 feet. This discharge was passed over a weir of the simplest form, and the head noted by a sufficient series of observations. Then the weir was changed in any way, and the head again noted. The difference of head determined the effect of the altered conditions, without any need of directly measuring the discharge, and free from the inaccuracies to which such measurement is liable.

Velocity of approach.—By velocity of approach is meant the quotient of the quantity passing over the weir by the section of the channel of approach.

In a weir without end-contractions, the velocity of approach is simply dependent on the depth on the weir, and not on the width of the weir; hence experiments were chiefly made on a weir of this kind. To vary the velocity of approach the timber bottom of the channel of approach could be placed at varying distances from the weir-crest. The heads were measured by hook-gauges in cisterns, communicating by tubes with the points where the heads were to be measured. Gauge No. 1 communicated with a gas-pipe placed immediately behind the weir at the bottom of the channel of approach; gauge No. 2 with an opening in a plate of glass in the side of the channel of approach, 6 feet behind the weir.

Let h be the head due to the velocity of approach. Then ch is the quantity to be added to the actual head over the weir to allow for the velocity of approach, c being a coefficient which it was the object of these experiments to determine.

For a weir without end-contractions, the heads being measured at gauge No. 2, 6 feet behind the weir, the value of c was not very far from constant, and on the average it was 1·5, the depth of the channel of approach below the weir-crest varying from 0·5 to 2·6 feet. A table of values of c in different conditions is given.

Experiments were then made with boards placed at the ends of the weir to produce end-contractions. These showed that the effect of velocity of approach is greater with two end-contractions than with one. It increases as the width of the channel occupied by the weir decreases. It varies with the depth of the channel in the same way as when there is no end-contraction. The general value of c in this case is 2·05. The heads were measured at gauge No. 2.

When the heads measured at gauge No. 1 were compared with those measured at gauge No. 2, the former were always greater. It appeared, therefore, that in the triangular space immediately behind the weir, an excess of pressure was produced. This excess of pressure was nearly a constant fraction of the head, due to the velocity of approach, for each position of the bottom of the channel of approach. If excess of head at gauge No. 1 $= kh$, then for the weir having no end-contraction:—

	Feet.	
Depth of channel below weir crest	0·5	$k =$ 0·36
" "	1·0	" 0·50
" "	1·7	" 0·54
" "	3·6	" 0·80

With end-contractions the difference between gauges 1 and 2 was somewhat greater.

In other experiments it was proved that the head measured by gauge No. 2, really corresponded with the true water-surface 6 feet behind the weir. Experiments were made to determine the curve of water-surface passing over the weir, and the extent of the wedge-shaped portion of water behind the weir, in which the pressure was greater than that at 6 feet behind the weir. These results are given in a diagram. The Authors conclude that the water is affected by the weir, both as to increased pressure at the bottom, and fall of the free-surface for a distance equal to about 2½ times the height of the weir-crest above the bottom of the channel. Hence, in a weir intended for measurement, the free flow of the water should not be interfered with within that distance by screens or non-uniformity of the channel. The head should be measured at a point beyond that distance.

Flow over sharp-crested weirs.—Two weirs were used, one 5 feet long, with heads varying from 0·07 to 0·83 foot. The other 19 feet long, with heads varying from 0·47 to 1·63 foot. The 5 feet weir was without end-contractions, the crest being formed by a nickel-plated steel straight-edge. The heads were measured by a hook-gauge in a cistern connected with a point 6 feet above the weir. Dams across the stream below the weir formed a larger and a smaller gauging basin. The formula which was found to represent the results of the experiments was

$$Q = 3 \cdot 33\ L\ H^{\frac{3}{2}} + 0 \cdot 0065\ L,$$

where H is the head above the weir, and L the length of the weir.

The possible sources of error in the experiments are discussed at

length. The effect of the velocity of approach is shown to be best allowed for by adding to the actual head H a quantity equal to $1\cdot 8h$, where h is the head due to the velocity of approach.

The arrangement of the 19 feet weir is too complicated for explanation, and the original Paper must be referred to. The formula obtained for this weir was

$$Q = 3\cdot 291 \text{ L H}^{\frac{3}{2}} + 0\cdot 004 \text{ L},$$

the differences not exceeding, except in one defective experiment, $\frac{8}{10}$ of one per cent. The correction for velocity of approach was doubtful, as the conditions in the channel of approach were not strictly normal. It appeared that the best correction was $2\cdot 4h$; although apparently large, this correction only affects the coefficient in the weir formula by one per cent. with the largest depth of water on the weir, and by much less for smaller heads. The excess of pressure immediately behind the weir was $2\frac{1}{2}$ times the head due to the velocity of approach.

Francis's experiments on sharp-crested weirs.—The experiments with the 5-feet and 19-feet weirs, gave results showing a constant difference, the origin of which could not be traced. To find a common formula generally applicable, Francis's experiments are brought into the reckoning, with the additional knowledge of the effect of velocity of approach now available. Calculation of those of the Lowell experiments, in which the depth of the channel of approach was the only important variable, showed that in Francis's experiments the head to be added for velocity of approach, in the case of weirs with end-contractions, was

			Foot.	
Series . .	3—5	Head on weir	1·03	$c =$ 1·47
„ . .	8—9	„	0·82	„ 1·33
„ . .	11—12	„	0·64	„ 0·89

the differences in the value of c do not seem the result of any law, but are probably due to the difficulty of measuring the small quantities affected by velocity of approach. For this reason an average value, $c = 1\cdot 35$, has been taken in correcting Francis's results for velocity of approach.

For weirs without end-contractions the channel of approach was more uniform as in the Author's own experiments, but the heads were measured within the area of increased pressure. These results are corrected by taking $c = 1\cdot 25h$.

The formula obtained was

$$Q = 3\cdot 313 \text{ L H}^{\frac{3}{2}} + 0\cdot 006 \text{ L}.$$

The general formula finally adopted by the Authors, from comparison of their own and Francis's experiments, is

$$Q = 3\cdot 31 \text{ L H}^{\frac{3}{2}} + 0\cdot 007 \text{ L},$$

for a sharp-crested weir without end-contractions, and without velocity of approach. It is based on experiments in which the

depths on the weir range from 0·07 to 1·63 foot. It is probably not applicable to smaller depths, but there is no reason to doubt that it may be applied to greater depths when a correction has been made for velocity of approach.

Weirs with wide crests.—The result sought was to find a law by which the depth on a wide-crested weir could be corrected so as to render the formula for sharp-crested weirs applicable. The results show that for a certain depth on the weir no correction is necessary; for smaller depths the correction is minus, and for greater depths plus. The Authors obtained

$$C = 0 \cdot 2016 \sqrt{\{y^2 + 0 \cdot 2146\, w^2\}} - 0 \cdot 1876\, w,$$

where C is the correction to be added to the observed head; w the width of the crest, y the difference between 0·807 w and the depth on the crest. The formula may probably be applied to crests not exceeding 2 or 3 feet in width, and to large depths on the weir; probably not when the crests are less than 1 inch wide, or the depths less than 0·1 foot.

Weir with upstream edge rounded.—The rounded edge has practically the same effect as lowering the weir-crest. The correction for a rounded crest is

$$C = 0 \cdot 7\, R,$$

where C is to be added to the measured depth, and R is the radius of the crest. The formula is limited to R less than $\frac{1}{2}$ inch, and depth on weir greater than 0·15 foot.

Discharge over a submerged weir.—A table of values of the coefficient of discharge is given.

Effect of end-contraction.—This is represented by the expression,

$$C = b\, H,$$

where C is a correction to be subtracted from the actual length of a weir with end-contractions, to reduce it to a weir without end-contractions, and H is the depth on the weir. Values of b varying from 0·04 to 0·115 were found. The chief value of these experiments is that they show that a weir with end-contractions should be avoided when accurate measurements are desired.

W. C. U.

Experiments on the Motion of Waves passing through a contracted Channel, either in the middle or at the extremity of a Canal.

By A. DE CALIGNY.

(Comptes-rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 102.)

The experiments were conducted on an artificial canal, in Cherbourg Arsenal, with the object of completing some investigations on the effects of waves passing between converging embankments, which formed the subject of two previous communications.[1] The canal, and the generation of the waves, by impulses produced by a body suspended in the water and moved by a steam-engine, were described in a recent article.[2]

When saw-dust was spread on the surface of the water, where vertical planks on each side contracted the channel, it was dispersed by the waves so as to leave the water clear for some distance above and below the contraction. The effect of the waves, however, on the bottom, where a layer of sand was spread, was modified considerably by the reaction from the vertical partitions; though by placing a sloping plank perpendicularly to these partitions, a definite scour of the sand above and below was produced. The direction of motion of the waves was, accordingly, reversed; and a reservoir having the same depth as the canal, but much wider, was placed at the farther end. The mouth of the canal was reduced to half its width by inserting a vertical plank, resting at its upper extremity against one of the sides of the canal, and at its lower extremity against a prolongation of one of the sides of the reservoir, so that the waves were deflected to the wider part of the reservoir. The sand strewn over the bottom above the mouth, and even tolerably near it, was not carried by the wave-motion into the reservoir; but a thin layer of sand placed at the entrance to the reservoir was washed away, as by a current, to some distance from the mouth of the canal. Saw-dust spread at the entrance was soon swept a long way off. A greater contraction of the mouth of the canal increases the distance to which the sand is carried into the reservoir, and also renders the scour more complete.

L. V. H.

The Regulation of River-Channels, deduced from the Widths of the Bed of the Garonne. By —. FARGUE.

(Annales des Ponts et Chaussées, 6th series, vol. iv., 1882, p. 301, 2 pl.)

The river Garonne receives no important tributaries in its course through the department of the Gironde. The channel of the non-

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[1] Comptes-rendus de l'Académie des Sciences, vol. lxxv., p. 186, and vol. lxxvi., p. 30.
[2] *Ibid.*, vol. lxxxvii., p. 1020.

tidal river is regulated, for a distance of about 30 miles, by artificial banks, placed, for the most part, at an average uniform distance apart of from 490 to 525 feet, which is less than the natural width of the river. The effect of these training-works, which were carried out from thirty to fifty years ago, has been to lower the shoals, so that the navigation is much better now than it was in 1832. The summer water-level has, however, been gradually lowered considerably more than was anticipated, viz., 4¼ feet on the average; so that if the mean fall of the Garonne, instead of amounting to 1 in 5,000, had been considerably larger, the improvement-works might have been rendered useless. Instances are given of exceptions to the uniformity of width of channel, in places where the windings of the river tend to make the current shift from one bank to the other. At one place, where the channel, in shifting over, preserves a depth of 13 feet in summer (whereas at other similar situations the depth is only from 3 to 7¼ feet), the width of bed at the point of inflexion is only about 500 feet, whilst in the curve above it amounts to 650 feet, and in the sharp curve below it is 820 feet. Moreover, in this instance, the lines of the new banks were made to follow closely the original course of the river. At the Mondiet Pass, the summer depth of water fell to 2½ feet in 1865, stopping the navigation. The winding channel had, in this case, been regulated in precisely the opposite way to the former one; the width of bed had been made 560 feet at the upper bend, had been increased to 670 feet at the point where the main channel crossed over and the shore existed, and was reduced to 580 feet in the bed below. To remove the shoal, dredging was resorted to in 1865; and in order to render the improvement permanent, the river bed was narrowed from 670 feet to 540 feet at the point of inflexion in 1866; and after a second dredging, in 1867, the summer depth of the pass attained 7¼ feet, which has continued ever since, without further dredging. The pass at Cadroy, which up to 1870 had a summer depth of only 3¼ feet, was deepened permanently to 9½ feet, by narrowing the bed to 520 feet at the point of inflexion, the width at the bend above being 720 feet. Opposite Gortets the main channel shifts from the right to the left bank, without forming any troublesome shoal. The banks at this place are in their natural state; they are from 820 to 980 feet apart above, only 650 feet apart where the channel shifts over, and 1,000 feet apart below. Again, at Quinsac, where the navigable channel shifts from the left to the right bank, in a nearly straight but narrowed reach 800 feet wide, the depth is over 18 feet. Above and below this reach the river flows in a very curved double channel, with a total width of 1,300 feet and 1,650 feet respectively. Improvements, based upon the principle of narrowing the bed at the point of inflexion of the navigable channel, are being carried out; and already, at one place, an increase of 2½ feet in depth has been obtained. The above instances indicate that, in a river having an unstable bed, the width of the bed in the straight portion, where the channel changes

over from one bank to the other, should be less than at the bends, in order to maintain the depth at this point. This conclusion also results from the following considerations. Every year a river brings down a large quantity of solid matter, which it carries along in flood-time and deposits as the velocity of its current abates. This material has a tendency to deposit where the channel is shifting, which is the cause of the shoals at the points of inflexion in the summer. There is no similar liability for the channel in the bends to silt up, as it follows a well-defined channel close to the concave bank. Any deposit that occurs at a bend settles towards the convex bank, where it does not impede the navigable channel. It is, therefore, desirable to promote the accumulation of the deposit at this point, as the deposit would otherwise settle in the channel at the point of inflexion. This is attained by widening the bed at the bends, and reducing the width at the intermediate straight portions. In order to accomplish this in the most satisfactory manner, it is expedient to make the convex banks longer than the concave, so that both banks may be slightly convex at the narrowest point of the river. The minimum width, moreover, should be situated higher up the stream than the shoal, to the extent of from one and a half to twice the width of the bed at that point, in order that the maximum scour may occur at the shoal; for, owing to inertia, the greatest effect is always lower down the stream than the cause producing it. In the case of tidal rivers, it is pointed out that there is always a little discordance of action between the ebb and the flood, owing to the interval that separates cause and effect. Moreover, in the straight portion between the bends, the ebb prolongs its action along one bank, and the flood along the opposite bank, instead of tending to connect their scouring effects across the bed at the point of inflexion. In order to make the main currents of the flood and ebb follow the same channel, it is essential to reduce the width of the bed at the point of inflexion. In order to make the main currents of the flood and ebb follow the same channel, it is essential to reduce the width of the bed at the point of inflexion, giving both banks a convex form, as in the case of the non-tidal river.

The rules, accordingly, for the regulation of rivers with unstable beds, whether tidal or non-tidal, are: That the banks should gradually widen out as they descend, not regularly, but in a series of steps; that the bed of the river should be widened out at the bends, and reduced at the points of inflexion; and that both banks should be made convex at the narrowest point, the convexity on the one side being prolonged beyond the concavity on the other. Dredging should be resorted to for removing shoals formed by the deposit of materials too large to be carried off by floods, and especially for improving a river; but even continuous and far-extended dredgings will be of no avail unless the river-banks are trained upon correct principles.

L. V. H.

On the Damage done to the Southern Railway of Austria by the Floods in the Tyrol and Kärnten in the Autumn of 1882.

By Carl Prenninger.

(Wochenschrift des österreichischen Ingenieur und Architecten Vereins, vol. vii., 1882, p. 306.)

On the 10th September, 1882, a heavy snowfall occurred in the Tyrol and Kärnten, lasting for three days, and followed on the 15th by a strong sirocco. This rapidly melted the snow, and on the 16th and 17th the general manager of the Southern Railway received numerous telegrams from different points along the line reporting cases of the destruction of the line, or the danger in which it stood. The news became more alarming from day to day, and it was soon discovered that the floods extended over almost the whole of the districts through which the line passes.

On hearing this the Author, together with the general inspector of the Austrian railways, determined to proceed along the line in order to ascertain the amount of damage done.

The first serious damage was discovered at Ober-Drauburg, where the pier of a wrought-iron bridge of two spans of 28·4 metres (93 feet) each had been carried away; the bridge itself, which consists of continuous girders, was still intact, but the traffic over it was limited to passengers and light carriages. The water-level was 6 feet below rail-level, this being 1·6 foot above the extreme flood-level, as assumed in designing the bridge.

At Lienz all traffic was suspended, the embankment having been washed away in several places. At Nikolsdorf a watchman's house was destroyed, the station building resisting the floods only to fall a victim to those of October 28th. From Ober-Drauburg to Lienz, a distance of 11 miles, over 2,000 yards of line, consisting of some 90,000 cubic yards of earthwork, were totally destroyed. From Lienz the Author and his companion proceeded with the greatest difficulty; accompanied by guides, and provided with alpenstocks, they made their way *viâ* the Lienzer Klause and Mordbichl to Thal. The damage done on this portion of the line was very great, 440,000 cubic yards of earth, besides several platelayers' houses and other objects being swept away. The waters here rose 8·5 feet above what had previously been taken as extreme flood-level. At Thal matters were not in a much better state. More than 100,000 cubic yards of bank, as well as several buildings, were carried away. A portion of the line at Hof, consisting of 200,000 cubic yards, was destroyed; and at Innichen the station yard and several hundred yards of way were under water.

After passing Olang and Willenbach, the Author came upon a huge landslip containing above 250,000 cubic yards. Bruneck, which had suffered greatly, was reached after a three days' journey over a very much damaged road.

Between Waidbruck and Atzwang two embankments were partially destroyed, and the iron bridge at Röthele injured, a great portion of the south abutment having been carried away, so that the girders were supported by only a comparatively small amount of masonry.

The most serious damage done on the whole line was, however, between Atzwang and Blumau. A big embankment passing close along a bend in the River Eisack, and containing 170,000 cubic yards of stone and earthwork, was completely swept away; besides this, a watchman's house, two stone bridges, and the abutments of the bridge over the river at Blumau were very much damaged. Several works on the line below Bozen were carried away, the central pier and one of the abutments of the Leno bridge, between Roveredo and Mori, were destroyed, and the embankment between Mori and Seravalle was completely wrecked.

All damages were repaired with the greatest possible despatch, and by the 10th November the whole line, with the exception of 11 kilometres (6·5 miles) between Branzoll and Bozen, and 14·5 kilometres (8·5 miles) between Blumau and Waidbruck, was again opened for traffic.

J. R. B.

Closing the Breach of the Adige at Legnano in the Autumn of 1882. By P. Gallizia.

(Giornale del Genio civile, 1882, p. 770.)

On the 17th of September, 1882, an extraordinary rainfall, amounting in a single day to more than one-third of the average during the year, caused a sudden and excessive flood in the Adige, which in less than twenty-four hours rose to a height varying from 1 foot 6 inches to 4 feet 6 inches above the highest flood of the present century, causing a large breach in the bank and flooding a vast extent of country. As soon as the probability of an excessive flood was perceived strenuous efforts were made to raise the banks where necessary for a length of 50 miles. The breach occurred at a fortress a little above Legnano. It commenced by water making its way through the bank, and while attempts were being made to stop it by means of sacks, the unforeseen rupture of a siphon, together with the bursting of the bank in two other places, completed the disaster.

The city of Legnano was inundated to a depth of 10 feet, but fortunately, partly owing to energetic measures to divert it, the main body of the stream kept clear of the town, but more than 386 square miles of country, inhabited by a population of over one hundred thousand, were submerged to a depth which in some cases reached 25 feet. The breach in the bank was 650 feet long and 70 feet deep.

Operations for stopping up the breach were commenced while

the river was still in flood, and, after great difficulties had been overcome, the water was confined to its old channel on the 9th of December. The first step was to ascertain by soundings the proper position for constructing a dam outside the breach; this was accomplished with great difficulty, owing to the velocity and depth of the flood. The two ends of the bank were first strengthened to prevent the extension of the gap, and the dam was then continued in calmer water. The length of this provisional dam was just 1 mile, its width at the top 13 feet, with slopes of $1\frac{1}{2}$ to 1. For about three-quarters of the whole length it consisted only of earth-filling, but the central portion for a length of 1,300 feet, where the river was running in full force, required special precautions. Here a large quantity of stone was thrown over the bottom to protect it from further scour. Four or five rows of piles were driven and tied together in every direction, the piles being from 26 to 48 feet long, and about 3 feet apart, the space between the piling being filled in with bags of sand, and both inner and outer slopes protected by stones. This dam was constructed in layers of about 1 foot 6 inches in height over its whole length. The object of this was to reduce gradually and uniformly the height of the crest of the water flowing over the bank. A stone-apron, about 20 feet wide, was formed for the water to fall on to as it passed over the bank. Naturally a good deal of water leaked through the bank, and to reduce this another bank was formed of earth and stones some distance outside that already described. The water was thus raised between the two banks to nearly the level of the river. The work was carried out under considerable difficulties; the river being several times in flood caused a good deal of damage, and on one occasion carried away the piling.

An idea of the magnitude of the works may be formed from the fact that five thousand workmen a day were employed, and the materials used were three hundred thousand sacks, 26,000 cubic yards of large stones, 34,000 cubic yards of broken stones, two thousand piles, and about 260,000 cubic yards of earth. The expenditure up to the date of the Paper had been £50,000, and was expected to amount to £80,000, when the definitive reconstruction of the bank was finished.

W. H. T.

The Overflow of the Mississippi River. By LYMAN BRIDGES.

(Transactions of the American Society of Civil Engineers, 1882, p. 251.)

This great river drains a watershed of 1,147,000 square miles, and has an annual downfall of eighty trillions (80,000,000,000,000) of cubic feet of water, and a drainage of twenty trillions cubic feet, which is a ratio of 25 per cent. of the downfall per annum.

New problems and new conditions present themselves to a large extent in this river on account of the immense area of land

brought under cultivation, and of forest cut down, also from the gradual straightening of the river, which during the last hundred and sixty years has shortened its course 240 miles between Cairo and Orleans.

The annual rainfall on the watershed of the Mississippi and its tributaries would take the bed of the river, at the present rate of the current, three years to carry to the Gulf; or taking the ratio of 25 per cent. which is universally admitted, had it an average daily drainage, it takes nine months of the year at its maximum to carry off this immense volume of water. But when it is considered that the overflowed reservoirs on either side of the river, once filled, represent a volume of water nearly 50 miles in width and 12 feet deep from Cairo to New Orleans, or about twelve billions of cubic feet of water, which would take the maximum capacity of the Mississippi eighty-four days to carry away, even though it had no reinforcement constantly forced upon it above, it is conclusive that no system of levees below Red River, thus far constructed or proposed, can take away this yearly inland sea, having but 322 feet of fall from Cairo to the mouth of the Mississippi, and whose current is increased in flood stages from ½ mile an hour at medium stages to 3 miles per hour at flood stages.

Some other means must therefore be provided for the overflow above the maximum capacity of the river; and the Author asserts that the overflow has never been carried off by the Mississippi, and that its maximum capacity in time of floods never can be the medium or channel of the overflow at the flood-stage, without many years of labour and great expense in deepening the river-channel, and that the old natural channel or cut-off *viâ* the Atchafalaya River should be the main channel of relief aided by the Placquemine Bayou to the Atchafalaya, and the Bonnet Carré to Lake Pontchartrain.

Over $100,000,000 (£20,833,333) has been expended in the construction of the Mississippi levees already; and during the last fifteen years over 100 miles of these have caved in, and been lost to owners and the country.

J. C. I.

On the Improvement of Marsh-Lands. By G. Malaspina.

(Il Politecnico, August 1882, p. 449.)

The necessity for improving marsh-lands has been recognised from very early times, and in Italy great works have been executed for this purpose throughout the historic period. In 1806 and 1810 laws providing for such works and the method of raising the necessary funds were enacted, and the greatest work since undertaken was the improvement of the Tuscan *maremma*, commenced in 1828 and continued, by the method of rasing the level of the ground, for forty years.

The Venetian Marshes.—The lower part of the Venetian plain, embracing the provinces of Friuli, Venice, Padua, and Rovigo, is bounded by a broad band of marsh-lands which extend to the sea. These marshes are formed by the deposits of the Po, the Adige, the Brenta, the Bacchiglione, the Piave, the Livenza, the Tagliamento, the Isonzo and other rivers. Through the formation of these deposits the area of land is constantly increasing, and many once-flourishing seaports are now some miles from the shore, and on their ruins stand wretched villages, centres of fever and disease. Broad lagoons which formerly existed have silted up, and it is only by immense works that the Venetian lagoons have been preserved. During the last forty years the lagoon of Chioggia has silted up to the extent of one-half, and the remainder will probably suffer the same fate in another thirty years.

The action of the rivers in forming the delta is very irregular, though in ordinary times they have a tendency to form their own beds and to raise the ground on either bank up to the limit of average floods, yet occasionally, owing to exceptional causes, one river will overtop its banks, flow into the basin of another, cut itself a new channel, and cause irregular hollows and formations of deposit. This action is aggravated by the premature construction of artificial banks, which, though allowable in the upper parts of the river when the channel is already well-defined, ought not to be formed in low land, where the natural action of the river in raising the level of the ground is incomplete. In such cases it silts up its own bed, and the banks have to be constantly raised. The indiscriminate destruction of forests increases the evil by allowing the water to run off more rapidly. The result of these various causes is the formation of extensive tracts of land which must of necessity be marshy, as they lie too low for natural drainage into the sea, the river water being generally above the level of the adjacent land. In fact, there is not an acre of land in the middle and lower Venetian plain which is not dependent upon some special hydraulic arrangement either for protection against inundation, for drainage, or for irrigation; so that the whole district is divided among a network of societies governed by special laws for regulating the various water-rights. Another cause of the formation of the marsh-lands is that sand dunes are formed along the coast and offer further obstruction to natural drainage. Salt-marshes too exist on the coast, and these are the most unhealthy of all; the mixture of salt- and fresh-water causes the death and putrefaction of animals and plants, and the resulting miasma spreads inland.

Improvements effected in the Venetian territory.—The first attempt at draining these marshes was made in 1807, when a few farmers set up a small bucket-wheel, worked by three men, for draining a few acres. Presently another wheel was started, and by degrees horse-power and steam on a large scale were introduced.

These attempts were not always successful; but an area of 15,000 acres having been effectually drained with most satisfactory results, an impetus was given to similar enterprises in the district,

and very large tracts of useless and pestilential land have been converted into flourishing and healthy farms, villages and towns. The machines that have been found most successful are bucket-wheels and turbines.

The new law relating to the improvement of Marsh-Lands.—This law, founded upon the principle that the owners have no right to let their property remain a source of danger to the public, empowers the state to execute works when the owner will not. The law deals first with sanitary, second with agricultural and sanitary improvement combined. Half the expense of works of the first class (in which are included the construction of roads for placing the improved lands in communication with the nearest towns), is borne by the government, one-eighth by the province or provinces interested, one-eighth by the commune, and one-fourth by the proprietors, among whom are included those of neighbouring lands benefited by the work. The sums contributed from public funds are to be repaid when the land increases in value. The supply of drinking water to the improved lands is included among the works to be provided for.

Works of the second class are to be undertaken by associations, which may be either voluntary or compulsory, the former requiring the consent of all the parties interested; the latter being initiated by some public authority. In the former case all the expense is to be borne proportionately by those interested; in the latter, one-tenth is to be found by the nation, one-tenth by the province, one-tenth by the commune, the remaining seven-tenths by the proprietors. Provision is made for enabling the association to borrow from the treasury to the extent of three-fifths of the value of their property.

W. H. T.

The rational Employment of the Waterways of Germany.

By O. Intze.

(Wochenschrift des Vereines deutscher Ingenieure, 1882, pp. 381–385.)

After remarking on the very imperfect data available in Germany regarding the proportion of rainfall discharged by rivers, and the time of discharge, the Author passes on to a general consideration of the question, and for this purpose treats of—

1st. The head or source of a river;

2nd. The middle section;

3rd. The lower section or mouth.

The maximum discharge at the head is stated to vary from 100 to 300 times the minimum, according to the amount of rainfall, and unless means are available for keeping back or storing up this volume, the whole discharge will take place suddenly, and will work destruction on its way by tearing up the bed, bursting the banks, and laying waste the country. Sudden discharges in

the middle section would similarly injure the banks, and cause a silting up of the river-bed, thus forming, at low water, a serious impediment to navigation, while it would also admit of accumulations of ice, which, by heading up the water, would inundate the country around. At the mouth, too, injury would result from the formation of sandbanks on the one hand, and on the other from inundations due to the uncontrolled discharge of sudden great rainfalls.

The planting of forests throughout the area of the source would be an excellent means of modifying the suddenness of the discharge; but to apply this to all the rivers of Germany would be a work of centuries; and to obtain complete data regarding the extent, volume, and duration of rainfalls would take generations to carry out. The Author recommends, therefore, the collecting of the surplus discharge in natural basins, or, if these are not available, in artificial reservoirs formed by throwing a dam across a valley, such as have of late years been extensively carried out in France and Belgium, and have proved most beneficial, not only for the supply and improvement of rivers, but for purposes of irrigation also. Such works have, however, also proved disastrous; for example, the huge dam across the Habra valley (Algiers),[1] the Sheffield reservoir-embankment, and the older and very massive dam at Puente, in Spain. In the Habra dam the weakest part was shown to be at a point 33 feet below the top. Details are given regarding the destruction of the Puente dam, the profile of which was exceedingly massive, and it is shown that mere thickness is not sufficient to ensure the stability of such structures, and that for this object a right construction and the best material and workmanship must be secured. Considered from this point of view, many of the French dams are too weak in the upper part, as also was the Habra embankment; while, on the other hand, that at Putnam (New York) is dangerously weak in the lower part. Profiles are given of the above-named dams, as originally constructed and as proposed by the Author.

For the improvement of rivers with small low-water discharges, movable weirs are recommended, such as are in general use in France and Belgium, and of late years in Germany also; while further down their course, and near their mouth, especially in tidal rivers, much may be done by carefully-designed regulation-works to improve navigation, to reduce the expense of dredging, and to prevent, or at any rate to diminish considerably, the disastrous consequences of floods. An excellent project by Franzius, of Bremen, for the improvement of the Lower Weser, is alluded to, in which he utilises the action of the tides; and it is also pointed out that Holland and Belgium have expended enormous sums in recent times for harbour improvements; and that, to hold her own in the competition with other countries, Germany must

[1] Minutes of Proceedings, Inst. C.E., vol. lxx., p. 447.

strive to the utmost with a view to make her water communications correspond to the increased demands of navigation. In further illustration of what France has done in this direction, the Author quotes the following works and their results:—

1. The drainage and irrigation of the plain of Forez (department of the Loire).

Thirty-two thousand acres of marsh-land have been drained at a cost of £21,600; the returns have been eightfold. Sixty-four thousand acres have been irrigated at a cost of £280,000, of which the State contributed one-fifth. The value of the land so irrigated has risen from about £20 to £70 an acre.

2. The Orédon Lake-reservoir for irrigating the numerous valleys at the foot of the Hautes Pyrenees.

Here a dam 55 feet high was built, capable of maintaining in the lake nearly 10 million cubic yards of water. The cost of this and 17 miles of channel amounted to £36,000. About 34,000 acres are brought under irrigation, and an enormous return (about fourfold) is expected.

3. The improvement of the elevated plateau of Dombes.

This plain comprises an area of about 280,000 acres, and formerly was most unhealthy. The improvements consisted in cleaning out 56 miles of water-courses, making 180 miles of road, sinking thirty-two wells of good drinking-water, and, subsequently, the drainage of 26,000 acres of marsh-land, together with irrigation works and railways, were taken in hand. In 1877, that is, twenty-four years after commencing the works, the death-rate of the people had fallen from 40·4 to 25·4 per 1,000; the population increased from 53 to 80 per square mile; and whereas formerly, amongst the recruits for the army, about 52 per cent. on an average were found unfit, in 1870 the return was only 9 per cent. Equally astonishing and satisfactory results have followed the construction of the Verdun Irrigation Canal, and the improvements of the "Landes" of Gascony.[1]

Herr Intze concludes by stating that France has spent many millions in the improvement of her inland navigation, both by the canalization of rivers and the construction of canals, and has expended an equal amount for the improvement of harbours; and appeals to the engineering profession to take advantage of every opportunity afforded for the systematic collection and arrangement of data with regard to river-improvement, and to urge on Government the necessity of speedy action.

W. H. E.

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[1] Further information respecting these works will be found in the Minutes of Proceedings, vols. liv., 304; lv. 234; lxvi. 402.

Flying-Ferry on the Snake River, Washington Territory, U.S.
By T. Doane.

(Journal of the Association of Engineering Societies, October 1882, p. 427.)

The Taxas "Flying-ferry," on the Snake River, Washington territory, consists of a scow, trimmed obliquely to the current by means of guy-ropes, one from each end of it, connected to and movable along an elevated wire-rope carried across the river, which is 1,300 feet wide, and secured to the bank at each side. The propelling force is derived from the stream, which, playing on the oblique up-stream side of the scow, propels it from bank to bank alternately. The scow is 60 feet long, 13 feet wide, and 29 inches deep, with a light-draught of 4 inches, and a load-draught, carrying a pair of horses with a buggy and two passengers, of 1 inch more. It is strongly railed at each side, in order to carry the wild cattle of the country, and is provided with landing-leaves, one at each end. Two catch-current boards are hung on the up-stream side, each 2 feet wide and 20 feet long, hung on pivots at their centres, so as to dip in either direction, as required, in order to receive the impact of the under-water. They are employed mostly when the wind blows strongly, when the passage could not be made without their aid.

The scow is trimmed so that each end alternately points obliquely up-stream, for going and for returning. The elevated wire-rope is of steel, and it stands 20 feet above the level of the river. It carries two pulleys framed in line, 6 feet apart, to each of which a standing wire-rope, about 70 feet long, is suspended. The ends of these ropes are connected by a manilla rope about 140 feet long, which passes over a pulley at each end of the scow, traversing the vessel for its whole length, and making three or four turns round a wheel at the centre. By this means the scow is held to the track, and is adjusted, by turning the wheel, to the required inclination. The scow, complete, cost £200.

There is warfare, occasionally, between the steamboat lines and the ferry-companies, when the smoke-stack fouls the rope; sometimes a stack goes down, sometimes a rope; but steamers can usually pass clear beneath the rope, by hugging one shore or the other, even at times of high water.

D. K. C.

Dock-Works at Ghent.[1] By M. Galland.

(Bulletin de l'Association des Ingénieurs sortis de l'École de Liége, new series, vol. vi., 1882, p. 255.)

The outer basin, in course of construction, will connect the Ghent docks with the Ghent-Terneuzen Canal. This basin will

[1] Minutes of Proceedings, Inst. C.E., vol. lxviii., p. 369.

have an area of 25 acres, and a minimum depth of 21⅓ feet; and two graving-docks will open into it, having lengths of 426 feet and 230 feet respectively. The works, which are being executed by contract for the sum of £133,165, comprise the excavation of the outer basin for a length of 1,200 yards; the construction of a quay-wall on the right bank of the canal, 3,400 feet long, and resting on a foundation whose top is 24½ feet below the water-level of the canal; the erection of 1,894 feet of retaining-wall on the two banks, and the formation of a culvert.

The depth to which the foundations of the quay-wall of the basin had to be carried (33 feet below the water), and the sort of quicksand in which they had to be excavated, led to the adoption of the compressed-air system, similar to that employed at the Antwerp quays.[1] In the first instance, the excavation for the foundations was accomplished for a considerable depth by dredging, the dredged material being conveyed away by means of a pump and floating tubes, after the method used for the enlargement of the canal, as previously described.[2] The quay-wall is 32 feet 10 inches high; 21⅔ feet wide at the base, and reduced to a width of 7½ feet at the coping by a batter on the face of 1 in 14 and six steps at the back, each 2 feet wide. The wall is built of brickwork, but is faced with hammer-dressed stone down to 11 feet below the coping. It rests on a concrete foundation 25¾ feet wide, 5 feet deep, and projecting 3¼ feet in front of the toe of the wall. As soon as the dredging has been carried to the desired depth along the site of the quay-wall, the working-chamber caisson, surmounted by removable plate-iron walls serving as a cofferdam, is floated into place between barges carrying a staging, from which it is suspended by chains. The wall is built on the top of the working-chamber, within the iron cofferdam, till its weight causes the caisson to rest firmly on the excavated bottom. Compressed air is then introduced into the working-chamber, and the workmen descend, through a plate-iron tube resting on the roof of the caisson, and complete the excavation for the foundations. The excavated material is thrown into a box, into which a lift and force-pump injects water; and by turning a stop-cock, the mixture of silt and water is driven out by the pressure of air in the chamber through a pipe communicating with the outside. The working-chamber is finally filled with concrete through vertical tubes; and as soon as the wall, which has in the meantime been gradually built up, is higher than the water, the iron sides are removed and used for another caisson, and the wall is then raised to its full height. The caisson and the movable enclosure are 83⅔ feet long, 25¾ feet wide, and have a total height of 22⅔ feet; the working-chamber is 6¼ feet

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[1] A description of these works will be found in "Rivers and Canals," vol. i., p. 77; also with more details in "Anvers aperçu sur ses Installations Maritimes et son Industrie," and in "Nouvelles Installations Maritimes du Port d'Anvers," MM. Couvreux et Hersent.—L. V. H.

[2] Minutes of Proceedings Inst. C.E., vol. lxviii., p. 369.

high, and the pressure of air in it varies from 0·7 to 1 atmosphere. The interval left between each successive caisson is 2 feet 7½ inches, which is filled up with concrete below, and with brickwork above. To ensure the connection of the separate lengths of wall, grooves (1⅓ feet by 1½ feet) are formed in the side faces of each length. The contractors have since found it expedient to do less dredging, so as to make the caisson rest on the bottom in a smaller depth of water, which enables them to commence the wall directly on the top of the caisson without the use of the plate-iron sides; and, moreover, the long and difficult operations with the floating stage are dispensed with, and, though the excavation inside the working-chamber is increased, there is no danger of dredging to too great a depth. These works are to be completed in April 1884, and will form a fitting supplement to the work of enlarging the Ghent-Terneuzen Canal, already completed to the Belgian frontier, at a total cost of £316,000. A quay, 300 feet in width, is to be formed all along the outer basin, and provided with sheds, and lines of way for wagons and travelling cranes.

L. V. H.

Stannard's Rock Light-Station. By General G. WEITZEL.

(Annual Report of the Light-House Board, 1882, Appendix, p. 87, 14 pl.)

Stannard's Rock is situated in Lake Superior, about 30 miles off from the southern shore of the lake, and 23 miles distant from Manitou Island, the nearest point of land. The rock emerges from 2½ to 3 feet out of water, and the portion above water is from 15 to 20 feet in diameter; but the area below is about ¾ mile in extent. A beacon was erected on the rock in 1868; it consisted of a conical stone structure supporting a wrought-iron spindle, with a cage at the top. In 1877, it was decided to erect a lighthouse on the rock. A site in Huron Bay was selected as the nearest suitable place for a depôt, for the preparation of materials for the work, though it was 51 miles from the rock. Work was commenced at the depôt (which was named Stannardsville) in June 1877, by erecting sheds and constructing a pilework wharf. The protecting pier for the lighthouse foundation was commenced at Stannardsville in the following month; it was formed of cribwork, about 95 feet square on the outer sides, and 13 feet high, planked and caulked at the bottom, top, and sides. It was divided into four watertight compartments, each having an internal area of 1,053 square feet, and it was ballasted with 600 cubic yards of stone, weighing 875 tons, which made its draught of water 11 feet. The protecting-pier was towed out to the rock by three steamers in 1878, and sunk over the site for the lighthouse. In July 1879 the lower portion, 15 feet in height, of the wrought-iron casing for the permanent pier, or lighthouse foundation, was lowered on to the rock within the protecting-pier, having been cut to fit the

inequalities of the bottom, which was about 12 feet below water. A canvas pipe, 4 inches in diameter, filled with oakum, was attached to the under edge of the casing; and when the casing was in place, it was weighted with 21 tons, to force the pipe into the small interstices. The space within the casing, 62 feet 5 inches in diameter, was then pumped dry; the rock was cleaned, and the depositing of cement concrete was commenced at the end of July, and continued daily till October 6. Work was resumed on the rock at the end of May 1880, by the erection of additional casing; and a few days after concreting was recommenced, and the pier was completed on the 3rd of August. This concrete pier is 35 feet high, 23 feet above water, 62 feet diameter at the top, and 62 feet 5 inches at the base; it is paved at the top with stone blocks, 6 inches thick, set in cement. The stonework of the lighthouse tower consists of Marblehead limestone. It was commenced on July 4, 1881, and the thirty-third and last course of the tower was laid on the 31st August. Towards the end of May 1882 the ice, which reached to 18 feet above the concrete pier, was gradually cleared away; and during June the ironwork of the tower was set up, and the lantern completed. The light was exhibited for the first time on the night of July 4, 1882. Duplicate fog-signal machinery has also been set up, to warn vessels off the rock in fogs, which are very prevalent in June and July.

A detailed account of the cost of the work is given in the report, of which the following is a summary:—

	£.
Labour and subsistence	18,736
Transportation	18,352
Materials	17,708
Labour	1,274
Tools and implements	1,014
Miscellaneous	2,244
Total cost of work	£59,328

L. V. H.

The Cost of the Drainage-Works of Berlin. By M. Knauff.

(Gesundheits-Ingenieur, 1882, p. 671.)

As an instance that the water-carriage system of drainage has failed in the performance of much that was expected of it, and that its extreme costliness may be reckoned among its chief defects, the Author brings forward the case of Berlin. He quotes the statement of Hobrecht, that the utilisation of the sewage on land is creating a perfect revolution in England, where towns are hastening to abandon the system of chemical treatment, entailing certain annual loss, for the more profitable and even remunerative plan of sewage-irrigation. He calls attention to the difficulty of obtaining official information with respect to Berlin, and in its absence he has, he states, based his calculations upon the most

moderate scale possible. The expenditure for sewers and pumping-stations for each of the seven radial divisions of the city is given, the total amount being 44,476,590 marks (£2,223,829), for a population of nine hundred and sixty thousand persons, living on an area of 3,049 hectares (7536·6 acres).

The cost of eighteen properties, acquired for sewage-irrigation, follows, the value per hectare varying from 3,711 marks (£75 per acre) to 870 marks (£17·6 per acre), or an average per the total area acquired, 5,322 hectares, of 2,203 marks for hectare (£44·6 per acre); the total cost for land being 10,660,300 marks (£533,015). For laying out, levelling, and draining the above land, the amount expended has been 7,778,028 marks (£388,901), the different items being given in detail. The above is equivalent to 1461·50 marks per hectare (£29·5 per acre). The rising-mains from the pumping-stations to the irrigation areas have cost 13,941,971 marks (£697,098), the total length of piping being 90,800 metres, the mean cost per running metre being 153·60 marks (£7 per yard), or, calculated on the land, 2619·70 marks per hectare (£53 per acre). An estimate follows of the loss of interest on capital during the execution of the works, amounting in all to 10,030,481 marks (£501,524). Adding together the above items, the Author estimates the total cost of the Berlin drainage at 86,887,366 marks (£4,344,368), being 90·50 marks (£4 10*s.* 6*d.*) per head of the population. He observes that it is impossible to believe that the above sum represents the final outlay; but even with these figures the expenditure already exceeds the estimated outlay of 71,500,000 marks by about fifteen million marks (£750,000). He next examines the annual cost for interest and maintenance, which he places at 6,457,221 marks (£322,861), or 6·70 marks (nearly 6*s.* 9*d.*) per head of the population. On looking at the question from another aspect, viz., the cost of the works to the town, and the annual cost of carrying on the irrigation works, the Author arrives at a total of 6,651,784 marks (£332,589), or 6·90 marks (nearly 6*s.* 11*d.*), per head of the population. These two estimates are remarkably similar, when it is remembered that the basis of calculation is widely different in each case. It is justifiable to assume that the annual cost of the drainage of Berlin is at least 7 marks per head, while the total deficit has to be borne by only about sixteen thousand householders, equivalent to a cost of upwards of 420 marks (£21) per house, without reckoning the increased payment for water from the town supply, the use of which has been trebled in comparison with former years.

There can therefore be no talk of the cheapness of the Berlin sewerage as contrasted with the cost of a chemical treatment of the sewage-water; and when it is remembered that in the foregoing calculations no value has been assigned to the manurial constituent of the sewage-water, it will be evident that there is scarcely any other plan of scavenging which is equally destructive of valuable fertilisers. Calculating the value of the liquid sewage, in accordance with the investigations of English

authorities (Lawes, Gilbert, and Hope), at 0·085 mark per 1,000 kilograms (1*d.* per ton), the worth of the 50,000 kilograms, or 50 cubic metres of sewage produced per head per annum, would amount to 4·25 marks (4*s.* 3*d.*), which is certainly a very low price for all the excreta of a human being. According to this estimate, the total value of the excrements of the nine hundred and sixty thousand inhabitants of Berlin would amount to 4,080,000 marks (£204,000), but the yield per hectare is by no means in proportion to this application of fertilising ingredients. Nor has the prediction of Hobrecht, the engineer of the works, been verified, that in consequence of the large area of land around the city available for irrigation, owing to the adoption of the radial system, there would be a competition for the sewage water. So far from this being the case, there is very little land in the neighbourhood suitable for the purpose, and the areas obtained compulsorily are ill fitted for irrigation. In spite, also, of all the publicity given to the matter, no farmers or cultivators have been found to make use of the sewage. The Author concludes that it follows, from all these facts, that the adoption of the radial system for the drainage of Berlin, apart from the plan of water-carriage, considered as such, was a gross technical and commercial blunder.

G. R. R.

The Removal of Rain-water from Towns, considered with reference to the Sewering of Berlin. By M. Knauff.

(Gesundheits-Ingenieur, 1882, p. 539.)

The Author quotes from a recent pamphlet by Waring, the engineer who designed the drainage of Memphis, the opinion that the admission of storm-water into the deeply-laid sewers of a town is generally a mistake, and nearly always wholly unnecessary. Waring affirms that rain-water is not in itself either a foul or polluting liquid, and can do no damage to streams; and that only in such cases in which surface-drains are liable to injure the roadways, to cause the flooding of cellars, or to interfere with the traffic, does it become necessary to provide sewers to carry away the rainfall. He distinguishes between underground drainage adopted as a matter of principle, and employed only as an occasional means of avoiding road-crossings, &c. Waring believes the large modern deep-laid sewers to be wrong in theory, and he sums up his remarks as follows:—"The present method of disposing of the rainfall is a survival of ignorance, and its continuance only shows the preponderance of traditional practices."

The Author traces the advocacy of the separate system to the writings of Chadwick, Philips, and Rawlinson, and instances the drainage of Alnwick, Tottenham, Leicester, and many other towns in England, in accordance with this system, over thirty years ago.

The advantage formerly claimed for the practice of admitting the rain-water into the sewers, in order, namely, that it might flush the ill-constructed culverts which at that time existed, no longer stands good under the improved formation of modern sewers. The larger the diameter of the sewers, the greater will be the tendency to the deposition in them of detritus; and the more completely the rain-water can be excluded, the more constant will be the flow in the sewers of the smaller diameter, necessary for the house drainage alone. An argument against the admission of the rainfall into the sewers is the impossibility of accurately ascertaining what volume of water may, under certain circumstances, have to be carried away in a given time. Excessive rainfall, under the mixed system, gives rise to evils of the worst kind, and even in Berlin, in May and September of the present year, the basements of the houses have been flooded by the overflow from the sewers. A consideration follows of the parties upon whom the charges for damages from sewage overflows should fall. The Author observes that the flooding of basements during storms, by the backing-up of the house drains, is a specific evil of the mixed-sewage system, which does not pertain to many other methods of town-drainage.

A Table is given of the heaviest known rainfall, in millimetres, in a number of towns, during specified periods of time, varying from 25 millimetres in 90 minutes (equal to 46 litres per hectare per second, or 4·1 gallons per acre), to 37 millimetres in 10 minutes (equal to 617 litres per hectare per second, or 55 gallons per acre).

The rainfall, assumed as the basis of calculation for the drainage of Berlin, was 23 millimetres per hour, only one-third of which is supposed to reach the sewers. The Author quotes the experiments of Hawksley, Bidder and Haywood in 1857–8, who came to the conclusion that not less than 50 per cent. of the rainfall must be carried away by the sewers, and this amount is usually provided for by English engineers. A formula based on this percentage follows, and the Author shows that the area of the Berlin sewers is insufficient. Their insufficiency can only be remedied by means of numerous storm-overflows, and if the use of such overflows be permitted, there is no reason why the main outfall should not be of perfectly arbitrary size, with hundreds of outlets to guard against the possibility of overfilling. Hobrecht's opinion on the advantages claimed for the separate-system is adduced. The assertion that a twofold system of sewers, in the case of the separate-system, must be more costly than a single one, is examined, and the arguments quoted by Fegebeutel, for and against each plan, are stated in detail. The Author is of opinion that the facts of Fegebeutel are derived from the writings of Baldwin Latham. The quality of street-washings, which have usually been asserted to be nearly as rich in manurial ingredients as domestic sewage, is examined, and the Author gives a Table of the amount of nitrogen, which would be partially or wholly lost by keeping the rainfall from the sewers. He states that on the road surfaces of a town of one hundred

thousand inhabitants, the excrementitious matters of the population would contain, in nitrogen, approximately as follows:—

		Nitrogen. Kilograms.
Dung and urine of 4,000 horses	=	6,859
" " 5,000 dogs and cats	=	500
" " birds and poultry	=	25
Leather cuttings, etc.	=	216
Let it further be assumed that the third part of the excreta of 9,000 men (a quarter of the adult male population) void their excreta improperly on road surfaces, or courtyards, the nitrogen $= 9{,}000 \frac{5\cdot48}{3}$.	=	16,440
Total	=	24,040 kilos. or 52,998·5 lbs.

or equivalent in round numbers to 66 kilograms (145·46 lbs.) of nitrogen per diem, and in the one hundred and fifty-one rainy days of the year, to say, 10,000 kilograms (22,046·2 lbs.) The excreta of one hundred thousand persons would contain about 433,050 kilograms (426·2 tons) of nitrogen, and the proportion thereof, present in the sewage on the one hundred and fifty-one rainy days would be, deducting the above 16,440 kilograms = 162,712 kilograms of nitrogen, or about sixteen times the amount credited to the rain-water from the street-surfaces. The Author assumes, then, that 94 per cent. of the nitrogen of a population would be found in the sewage, as against 6 per cent. in the rainwater from the roads. The contrary opinion of Way, that the washings from the streets are as rich in manure ingredients as the house drainage, is quoted. The impossibility of keeping road-detritus out of the drains, and the fallacy of deep gutters or channels for street-drainage, is shown. The views of Hering are examined and quoted at length, and in conclusion the Author remarks, with respect to the drainage of Berlin, that, in the construction of new roads, the crown of the roadway must be considerably lowered; that proper observations must be made of the proportion of the total rainfall which has to be carried away by the sewers; that for the sections of the sewering still to be carried out, a heavier rainfall than 23 millimetres (0·9 inch) per hour must be provided for; that, in the portions of the sewers which are executed, numerous additional overflow channels must be made, as the provision of storm-outlets alone does not appear to be sufficient to check inundation. The street-gullies must be fitted with improved gratings; the ventilation of the existing and future sewers must be carried out on a better system than at present. The stoneware pipes, forming the house-connections, must be tested more carefully, as respects their imperviousness and durability; the joints of such pipes must be made in cement. Proper back-flow traps must be provided for all the soil-pipes in cellars and the junction between the down-pipes (of iron), and the trap must be made of iron pipes with lead joints.

G. R. R.

The Theory and Accurate Working of the Automatic Scavenger.[1]

By the ABBÉ F. MOIGNO.

(Cosmos-les-Mondes, January, 1883, p. 110.)

The Author states that the only serious objection made to this invention is the following one. Is it not possible to determine beforehand what dimensions should be given to the scavenger in order that, as its name implies, it should continue to work without interruption for an indefinite period? Mr. Mouras, the inventor, has carefully studied this question, and has prepared a complete solution by the facts now brought forward. A Table has been constructed for all sizes of tanks, from an area covered of $\frac{1}{2}$ square metre (5·38 square feet), to 20 square metres (23·9 square yards), and for each number of persons contributing to it, from one to two hundred. This Table indicates at the same time, (1) the depth the tank should contain of liquid matters; (2) the thickness of the upper stratum of solids undergoing decomposition (désagrégation); (3) the depth to which the overflow-pipe must be submerged; and (4) the capacity of the tank in cubic metres. A constant depth of one metre for every size of tank would be all that would be necessary, if nothing but excreta could enter the tank. A small correction has, however, to be made for detritus and foreign matters. The calculations have been based on an assumed depth of 1 metre, and it has been found (1) that each member of an average population adds daily a volume of fecal matters equal to $\frac{2}{10000}$ of a cubic metre (0·35 pint); (2) that for the complete solution of the floating solid matters a period of thirty days is required, if the superficial area is such that the thickness of this top layer does not exceed 0·075 metre (2·95 inches). With these facts established, the necessary proportion can be calculated with mathematical accuracy. The Author recapitulates the advantages previously claimed for this invention, and states it to be the only one which renders it possible to send all the dejections, liquid and solid, to the sewers. The Table, which gives the dimensions for tanks of all sizes, calculated from the formulas which follow, is not suitable for an abstract.

Assuming the daily volume of excreta per head to be 0·000250 cubic metre (0·44 pint), which is excessive, and taking the base of the tank as equal to one-tenth part in square metres of the number of the contributory population, the depth of the tank p can be ascertained from the following formula $p = 1 \cdot 00 \text{ metre} + (\text{N} \times 0 \cdot 02)$, N being equal to the number of persons, and 0·02 a constant to allow for detritus. The depth of undecomposed solids may be found from the following formula, E being the thickness of the layer, $\text{E} = \frac{0 \cdot 00025 \text{ metre} \times \text{N} \times 30}{\text{S}}$. Here S is the area of the

[1] Minutes of Proceedings Inst. C.E., vol. lxviii., p. 350.

base of the tank in metres, and N the number of persons using it. Finally, the length of the submerged portion of the overflow-pipe is ascertained by the addition of 10 centimetres (3·93 inches) to the above thickness, or a constant depth, in round numbers, of 0·175 metre, say 18 centimetres (7·08 inches).

G. R. R.

Groningen Waterworks. By B. Salbach.

(Glaser's Annalen, 1882, p. 71.)

The town of Groningen, situated in the north-east of the Netherlands, with a population of forty thousand, was, previous to the construction of these waterworks, entirely supplied from wells for drinking purposes, but the quality of the water latterly was such as to render imperative that a purer supply should be obtained from some other source. The neighbouring Zuidlaardermeer and Leekstermeer, lakes of considerable extent, first came under consideration, but the basins in which they lie and the soil through which their feeders flow being of a peaty nature, rendered their waters unfit for drinking. It was finally decided to take the supply from the River Drentsche Aa at a point about 6 miles south-east of the town, the water being generally clear, of good quality, and with but slight variation in its level throughout the year, and affording a supply amply sufficient for the requisite amount, viz., 528,466 gallons per twenty-four hours (that required for street watering being obtainable direct from the river passing through the town). A chemical analysis of the water is given, the amount of organic impurity being 1·78 part in 100,000. Experience afterwards proved that in winter considerable discoloration arose from the influx of waters stained with peat. To get rid of this discoloration, a small quantity of potassic sulphate of alumina (*Schwefelsaure, Kalithonerde*) is added to the water before its entering the filter, which has the effect of separating the alumina from its hydrate, the latter absorbing the colouring matter and being precipitated with it to the bottom of the tank. The quantity of potassic sulphate necessary for the purpose has been found to be about $\frac{1}{8000}$ part by weight, and this proportion is injected into the cylinder of the pump (drawing the supply from the river) at each stroke from a small pump working in unison. The amount required for clarifying the full supply of 528,466 gallons per twenty-four hours is 662 lbs. (300 kilograms).

The pumping-engine, subsiding-reservoirs, and filter-beds, of which latter there are three and two respectively, are situated near the point from which the supply is derived, the level of the dam-tops being 9 feet 10 inches above mean water-level of the river.

The water is conducted from the river by a pipe $9\frac{3}{4}$ inches diameter into a well, from which it is pumped into one of the three

subsiding-reservoirs, each with a capacity of 176,155 gallons: they are lined with brick, the maximum and minimum water-level above that of the filter being 3 feet 3 inches and 1 foot 7½ inches respectively. The latter are each 12,912 square feet in area, and capable of filtering 528,466 gallons, or 84,758 cubic feet daily (6½ cubic feet per square foot of area). They also are lined with brickwork; the filtering material being composed of a layer of coarse gravel 8 inches thick, covered by another of lake mussel-shells 12 inches thick, the top being of moderately fine sand 1 foot 8 inches thick, and depth of water 3 feet 3 inches.

There is a pair of engines, either of which is capable of pumping the required supply. The diameter of the cylinder in each is 17 inches, and stroke 27½ inches. The ram of each high-pressure pump is 8½ inches diameter, and those of the pumps drawing the supply from the river 8⅞ inches. There are two boilers, each with 484 square feet of heating surface, and working up to a pressure of 90 lbs. per square inch.

The main leading from the pump-house to the water-tower is 5¾ miles in length, and 9¼ inches in diameter. The tower, which is about 1 mile from the town, is surmounted by a circular wrought-iron tank of 40 feet diameter and a water-depth of 19 feet 8 inches, with a capacity of 154,135 gallons, the surface of water being 105 feet (32 metres) above the ground-level.

The works occupied less than a year in construction.

D. G.

Results obtained with Klönne's Generator-Furnaces for Gas-Retorts. By — Kros.

(Bulletin de la Société Technique de l'Industrie du Gaz en France, 1882, p. 80.)

During the course of last year Mr. Klönne, of Dortmund, erected ten benches of retorts on his generator system at the Municipal Gasworks at the Hague. Five of these benches were worked during the six winter months, and then put out of action for making some alterations in the tar-pipes, some difficulty having been encountered in removing the tar.

The benches of ten furnaces consist of two rows, each of five beds of retorts, placed back to back. Each arch is 8 feet 9 inches wide and 9 feet 6 inches deep, and contains eight retorts 23¾ inches by 15 inches. The generators are 5 feet 5 inches high from the furnace bars, and of an average length of 3 feet 5 inches, the furnace opening being 6¼ square feet area.

The first trial was with five benches, and the observations were taken a few days after they were fired. Pelton and New Pelton-Main coal was used with five-hour charges (*i.e.*, five charges per twenty-four hours). The coal and coke used were carefully weighed, but the gas produced could not be measured as other

retorts were in use at the same time, the gas produced was therefore estimated.

The results of the first trial were as follows:—

Coal carbonized per bench per day . . .	18,081 lbs.
Gas produced " " . . .	81,933 c. feet.
" " per retort " . . .	10,242 "
Coke used per 100 kilos. of coal carbonized .	29·30 lbs.

The temperature became excessive during the trial, and it was found necessary to moderate it or to use a larger quantity of coal. It was feared that from this cause stoppages would arise from thick tar, and, after the first trial, the retorts were worked for about a month at a lower temperature, that is at about the same temperature employed with the ordinary settings, the five-hour charges being continued as before. During three days' working the following results were obtained:—

Coal carbonized per bench per day . . .	16,250 lbs.
Gas produced " " . . .	72,081 c. feet.
" " per retort " . . .	9,009 "
Coke used per 100 kilos. of coal carbonized .	31·70 lbs.

The tar was somewhat thick, but not thicker than with ordinary firing, and certainly not more so than where through retorts are used. A third trial, made under similar conditions, but with six charges, instead of five, per twenty-four hours, gave as follows:—

Coal carbonized per bench per day . . .	18,787 lbs.
Gas produced " " . . .	83,348 c. feet.
" " per retort " . . .	10,418 "
Coke used per 100 kilos. of coal carbonized .	25·62 lbs.

The duration of this trial was not long enough to show whether the tar would become thick by continued working. It may, however, be expected that this would be the case, as in other places it is considered advisable with the Klönne furnaces to use Westphalian coal, which is not liable to this inconvenience. The clinkering of the furnaces was performed twice in twenty-four hours, and caused no trouble. After the trials, the interiors of the settings and generators were found to be in good condition, only a few of the furnace-tiles requiring renewal, after which they would be again put to work without further repairs.

It is mentioned that at another works two beds of retorts with these generators have been worked for nearly two years, having only been once let down for trifling repairs due to imperfect construction; and another instance is given of continuous working for five hundred days.

C. G.

On the Stoppage of Gas-Retort Ascension-Pipes.

By — Coudurier.

(Bulletin de la Société Technique de l'Industrie du Gaz en France, 1882, p. 97.)

After making unsuccessful trials of the various means proposed for avoiding stoppages in ascension-pipes, the Author endeavoured to devise an arrangement which, although not entirely preventing the obstructions, would admit of the easy clearing of the stopped pipes. He asserts that the plan he adopted not only effects this, but that it retards the obstructions to such an extent that the ascension-pipe of a retort worked at a very high heat which formerly required cleaning daily now works for a month without stoppage. Formerly, when high heats were not employed in the distillation of coal, the tar condensed in the ascension-pipes and flowed down them in a liquid state into the retort mouthpieces, from which it was removed at each time of drawing, but, at present, working with much higher temperatures, this state of things is changed; the lower parts of the ascension-pipes are raised to a high temperature, and the gas issuing from the retorts, being also much hotter, carries with it nearly the whole of the tar in a state of vapour into the upper parts of the ascension-pipes. The condensation of the tar commences there, and it runs down the sides of the pipes to the hottest parts, where it undergoes a partial distillation and is converted into pitch, which stops the pipes.

The object aimed at was to arrest the primary condensations of the tar at a point in the ascension-pipes where the obstruction could be easily removed, through an opening covered with a lid similar to that of a retort mouthpiece. For this purpose the Author proposes to fix a wrought-iron box 3 feet 3 inches high and 15¾ inches by 12 inches midway in each ascension-pipe. The increased area of this box, as compared with the ascension-pipe, diminishes the velocity of the gas and favours the deposition of the tar. An opening 27 inches by 8 inches is formed in the box, which is closed with a cover, secured by cross-bar and screw like the mouthpiece lids. Two horizontal wrought-iron shelves are placed in the box, one with a space in front, and the other with a space at back, so as to divide the box into three compartments, and to receive the condensed matters, the shelves being removable through the opening for cleaning. With this arrangement the clearing of the box and pipes becomes very simple. The cover is taken off and the shelves removed with a pair of tongs and cleaned, and the deposits at the bottom of the box removed. If pitch has formed in the lower portion of the ascension-pipe it is easily removed, as the pipe is short and can be got at from both ends.

This arrangement has been at work at Sens for several months with great success.

C. G.

Improvement in Lighting certain Streets of Berlin.

(Deutsche Bauzeitung, 1882, Nos. 79, 90.)

Simultaneously with the lighting by electricity of a certain part of the German metropolis, streets adjacent thereto have, for the purposes of comparison, and at the same time diminishing the sudden transition from an ordinary to a brilliantly-lighted thoroughfare, received increased illumination by gas, as enumerated under the following heads:—

(i.) The electric lighting, under contract with Messrs. Siemens and Halske, consists of 36 arc-lamps of about 500-candle power (British standard) each, replacing until midnight 105 ordinary gas-lamps, 17-candle power, consuming 195 litres (6·9 cubic feet) per hour; after midnight the illumination by the original gas-lamps is resorted to.

The lighting by gas is effected

(ii.) By 54 Siemens' regenerative burners of 130 to 160-candle power, the consumption of each being 750 litres (26·5 cubic feet) per hour till midnight, and then reduced to 400 litres (14·1 cubic feet) per hour.

(iii.) By 32 lamps of 100 to 110-candle power, consisting each of three flat-flame burners (Bray's system), and consuming 1,200 litres (42·4 cubic feet) per hour; and

(iv.) By 30 lamps of 100 to 110-candle power, consisting each of six flat-flame burners forming a ring, as in Lacarrière's pattern, the consumption being the same as in (iii.).

The last two methods are replaced by the ordinary gas-lamps after midnight.

Calculating the simple working cost of each system, per surface illuminated, the results in pfennige per arc (pence per 1,000 square yards) per hour are, for (i.) 7·61, for (ii.) 7·20, for (iii.) 10·24, and for (iv.) 9·41. The figure for the lighting by electricity is obtained from the contract price of 26,040 marks (£1,300) for one year, or 1,900 hours. If the interest on capital, cost of plant, cost of repairs, and depreciation be allowed for, that figure would be about 12·52; and allowing still further for reserve machinery in case of accident, and rent of engine-room, &c., would probably amount to 15 at least. For gas the price is taken as that charged by the municipality, who are their own manufacturers, viz., 13½ pfennige per cubic metre (3*s.* 9¼*d.* per 1,000 cubic feet); if their actual cost price of 10 pfennige (2*s.* 10*d.*) were taken, the figures would be reduced for (ii.), (iii.), and (iv.), to 5·4, 7·68, and 7·06, respectively.

No account has been taken of the merits of the different illuminations on other grounds, but the figures apparently point to the conclusion that electric lighting is still a luxury. A better com-

parison is hoped to be afforded at the close of the year during which this lighting is to be continued, and which commenced on the 20th September, 1882.

F. J.

In continuation of this subject, Mr. v. Hefner-Alteneck (Wochenschrift des Vereines Deutscher Ingenieure, 1883, p. 41), taking the electric light as equivalent to three of the gas burners, obtains the following comparative cost per hour:—

Siemens' regenerative burners	. . . .	32
Lacarrière's "	. . . .	48
Bray's "	. . . .	48
Electric light	. . . .	38

This is assuming the contract value of 360 candles for the electric light, whereas it is in reality 880 candles.

Other correspondents dispute these values on the ground of wrong and not equivalent data in the two cases. In reply, it is stated that the price of gas was believed to be very nearly the cost price, and were steam-engines to replace the gas-engines now in use the figures would be still more favourable for electric light.

F. J.

Arrangement for Registering the Speed of Trains passing over Bridges. By T. H. M. Waldorp.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1882, p. 287.)

The object in view is to register the velocity of trains while passing over bridges of long span; as it is thought desirable, for the maintenance and safety of such structures, to limit the speed of trains to 30 kilometres (18$\frac{3}{4}$ miles) an hour, particularly with the increasing weights now carried.

The arrangement consists of two parts: I°. At each end of the bridge is fixed a pedal, placed against the rail, so as to be depressed by each wheel of the train passing over the spot. Each depression of the pedal makes contact in an electro-magnetic circuit, which, in Part II°, acts on needles placed against a cylinder situate at any convenient distance. This cylinder is made to revolve by clockwork, at a uniform speed, and is covered with a sheet of paper.

While no wheels pass the pedals on the bridge, the needles mark straight parallel lines on the revolving paper sheet; but if contact is made, as above mentioned, the respective needles are momentarily deflected, and mark the instant at which each wheel passes the pedal in connection on the bridge.

The distance apart of the pedals at each end of the bridge being known, as also the rate at which the registering cylinder revolves, the speed of the passing train can be deduced by simple measure-

ment of the distance apart of the traces made by the marking-needles.

As a further check, the number of axles of which the train is composed is marked at the same time, and in the same way, by the needles deflecting at each contact in the circuit.

The whole is arranged and constructed by Mr. D. B. Kagenaar, Amanuensis-Mechanicus, at the Laboratory of the University of Utrecht. It is in use on the bridge over the Maas at Ravesteign, on the Dutch South-Eastern Railway, giving entire satisfaction.

H. S.

On the Resistance of Railway Trains and Locomotives.

By A. Frank.

(Organ für die Fortschritte des Eisenbahnwesens, 1883, p. 3.)

In the year 1862, Vuillemin, Guébhard and Dieudonné began a series of experiments with a view of discovering the amount of resistance encountered by trains at various speeds. In 1876 von Röckl, with the same view, experimented upon trains on the Bavarian State Railway. The formulas deduced from the experiments of the French engineers are:—

For goods-trains with a speed of from 12 to 32 kilometres,

$$w = 1 \cdot 65 + 0 \cdot 05\, v;$$

for passenger-trains with a speed of from 32 to 50 kilometres,

$$w = 1 \cdot 8 + 0 \cdot 08\, v + \frac{0 \cdot 009\, F v^2}{Q};$$

for passenger-trains with a speed of from 50 to 65 kilometres,

$$w = 1 \cdot 8 + 0 \cdot 08\, v + \frac{0 \cdot 006\, F v^2}{Q};$$

for passenger-trains with a speed of over 70 kilometres,

$$w = 1 \cdot 8 + 0 \cdot 14\, v + \frac{0 \cdot 004\, F v^2}{Q};$$

where w = resistance of train in kilograms per ton;
F = area of front surface of train in square metres;
Q = weight of train in tons;
v = speed per hour in kilometres.

The coefficients were measured by a dynamometer-car placed behind the engine.

Von Röckl's formulas of resistance are:—

For cars, $K_1 = 0 \cdot 0025 + 0 \cdot 00000021\, v^3$ in kilograms, per kilogram of load; for locomotives, $K_2 = 0 \cdot 005 + 0 \cdot 00000021\, v^3$ in kilograms, per kilogram of load.

Resistance of curves, $K_3 = \frac{0 \cdot 6504}{R - 55}$;
where R = radius of curve in metres.

The coefficients in this case were found by shunting trains of known speed into trial sidings of different curvature and gradient, the movement of the trains being registered by a number of electric indicators, fixed at intervals of 20 metres along the sidings.

The Author, after criticising the formulas of Vuillemin, Guébhard and Dieudonné, remarks that the constant coefficient in von Röckl's formula for locomotives is too great; he maintains that a goods-engine will move forward at a slow and uniform rate down an incline of 3·8 to 3·9 in 1,000, whilst 3·2 in 1,000 is a sufficient fall to set a passenger-engine in motion. The coefficient in this formula should therefore be reduced from 0·005 to 0·0038 for goods-engines, and to 0·0032 for passenger-engines.

The Author in his experiments found that a train consisting of an engine and six carriages, weighing 130·5 tons attains, without steam, a constant speed of 13·7 metres per second on an incline of 1 in 200, the resistance amounting to $\frac{130,500}{200} = 652$ kilograms; whilst von Röckl's formula gives the resistance at 3,690 kilograms.

In the Author's opinion, the formula of resistance should be of the following form—

$$W = \mu Q + \lambda F v^2$$

or per unit of weight,

$$w = \mu + \frac{\lambda F}{Q} v^2$$

μ and λ being co-efficients determined by experiment.

When the engines are impelled by steam, the formula becomes slightly altered, allowing for extra friction.

A number of experiments were made by the Author to determine the values of μ and λ, and to test the general accuracy of his formula. The section of the line on which the experiments were carried out was that between Metz and Courcelles, consisting of 9 kilometres of a 1 in 200 gradient, which is only broken once by about 300 metres of level at a point 5 kilometres from Metz.

The value of the coefficients μ and λ was found by employing the following equation deduced from the formula of resistance—

$$lg\,(v^2 - c^2) = lg\,(v_0^2 - c^2) - 2\,\frac{\lambda F}{M}\,S$$

where v = speed over a distance S;
c = constant speed;
v_0 = initial speed;
M = mass of body experimented on.

Had there been a second gradient of sufficient length on which to experiment, the values of μ and λ might have been found directly from the simultaneous equation thus possessed.

The value of F is variable; it depends on the nature of the engine or car, whether it be a passenger- or a goods-engine, a coach- or a goods-wagon, and whether it be loaded or empty; it also depends on the order in which open and covered trucks follow in a train.

The following are the values of μ, λ, and F arrived at by the Author:—

For passenger-engines	$\mu = 0\cdot0032$
„ three-coupled goods-engines . .	$\mu = 0\cdot0038$—$0\cdot0039$
„ coaches or goods-wagons	$\mu = 0\cdot0025$
„ cars or engines	$\lambda = 0\cdot1225$
„ passenger-engines	F = 7 square metres.
„ goods-engines	F = 8 „
„ a goods-wagon acting as shield to its follower	F = 1·7 „
„ each following coach or covered goods-wagon	F = 0·5 „
„ each empty open goods-wagon. .	F = 0·4 „
„ each loaded open goods-wagon. .	F = 1·0 „
„ each coach or covered goods-wagon following directly upon an open goods-wagon- extra	1·0 „

The Author's formula of resistance thus becomes for a goods-engine

$$w = 0\cdot0039 + \frac{0\cdot1225 \times 8 \times v^2}{Q};$$

for a passenger-engine,

$$w = 0\cdot0032 + \frac{0\cdot1225 \times 7 \times v^2}{Q};$$

for a coach or wagon of a train,

$$w = 0\cdot0025 + \frac{0\cdot1225 \times 0\cdot5 \times v^2}{Q};$$

in kilograms, per kilogram of load.

The resistances obtained by the experiments of Vuillemin, Guébhard and Dieudonné, are somewhat greater than those determined experimentally by the Author; the latter attributes the difference to the greater frictional resistance, and to the inferior state of the road on which the French engineers carried out their experiments. The value of F was the same in both cases.

If the values of μ and λ be increased as follows:—

For goods-trains, $\mu = 0\cdot004$;
For passenger-trains, $\mu = 0\cdot0034$;
$\lambda = 0\cdot18$

and these values substituted in the general equation of resistance, there results—

For goods-trains . . . . . $w = 0 \cdot 004 + \frac{0 \cdot 18\, F v^2}{Q}$;

For passenger-trains . . . . $w = 0 \cdot 0034 + \frac{0 \cdot 18\, F v^2}{Q}$.

These formulæ give for the coefficient of resistance values which, as shown by the following Table, are almost identical with those obtained by the French experiments.

——	v in metres per Second.	Coefficient of Resistance w.	
		By Experiment.	By Calculation.
For 23 goods trains of 39 wagons .	7·33	0·00487	0·00485
„ 4 passenger trains of 16 coaches	12·5	0·00598	0·00599
„ 7 „ „ „	14·4	0·00653	0·00683
„ 3 „ „ „	16·67	0·00805	0·00801

J. R. B.

On the Preservation of Iron Bridges. By E. PASCHEN.

(Glaser's Annalen, vol. xii., 1883, p. 47.)

The Author urges the growing necessity for the general adoption of some system, whereby the condition of existing iron bridges may be ascertained and recorded, and periodical inspections of all such structures be made in the future.

As regards the iron bridges erected in Germany, those upon the earliest constructed lines of railway, although not intended to carry the heavy class of locomotive now in use, were designed with such an ample margin of strength, and constructed in so careful a manner, as to be equal to the increased stress produced by the present type of engine; but with the progress of railway construction, investigation led to more familiarity with the direction and amount of strains upon bridge structures, and there ensued a desire, which seems to have become general, to economise the amount of metal to the utmost, basing the calculations upon the then existing conditions, and disregarding the possibility of the introduction of a heavier class of locomotive; so that, at the present time, in many bridges, the metal, at the transit of every train, is subjected to strains in excess of that which is assumed to be permissible.

This applies more to small than large spans, as the amount of increased load, due to the use of heavier engines, is proportionally

greater in the case of the former than of the latter. With the increase in the number and magnitude of bridges erected, a tendency to deterioration in the character of the work and material employed ensued.

The Author mentions the failure in some instances of the hinge ("Pendel") bed-plate, and advocates the use of the usual expansion roller-frame only, and, after enumerating the evils arising from various causes, such as the removal of the overhead transverse ties in the case of deep girders (causing lateral distortion), insufficient riveting at the intersection of lattice-bars, inattention to condition of paint, and the non-provision of a sufficient thickness of timber between the rail and the ironwork of the structure, points out the necessity for the employment of competent inspectors during the progress of the work, both at the place of manufacture and erection.

Reference is made to the Society of Architects at Berlin, which has directed its attention to the question, and proposes that the railway companies generally should institute a system of periodical inspections and reports as to the condition of their various iron bridges, and recommend that the observations should be divided into two classes, the first (general) to be made in respect of every bridge, and the second in special instances only.

"The general observations (to be made every five years) to include—

"1. Measurement of permanent deflection.

"2. Measurement of deflection caused by loading (at rest).

"3. Enumeration of those portions of the structure and rivets which may have already been renewed.

"4. Careful examination of plates at junctions of bracing with booms, &c.

"5. Careful examination of paint, and those places affected by rust.

"The special observations (to be made annually) to include—

"6. Deflection of the lower flange under a moving load.

"7. Distance apart of the top and bottom flanges.

"8. Length of the diagonals.

"9. Lateral distortion and vibration at the centre of the girders.

"All observations upon the structure when repeated to be, if possible, made by the same inspector."

In modification of the above, the Author suggests that the result of observations made by mere inspection should be kept separate from those obtained by loading, as the former could be made at any time at comparatively slight expense, and the most important of the defects discovered, whereas the latter would necessitate the presence of a sufficient number of engines of the heaviest class, and for the time being stop all traffic; he therefore proposes that subordinates should be first carefully instructed under the supervision of the chief inspector, and that afterwards it should be their duty frequently to examine the structures, a formal report from personal observation being made by him once

in two years, and that the load-test should be employed only once in ten instead of five years.

The special observations, it is suggested, should include the effect of temperature upon the length of the girders, the amount of movement in the roller bed-plate with trains moving in both directions, the comparative distances apart of the web-verticals, measured near the top and bottom flanges when the girder is loaded, and the lateral deflection caused by wind-pressure under the conditions of a loaded and unloaded girder.

The Author recommends that a book should be kept for the entry of the inspector's report, the information being under the following headings, viz., name, short description, and, where possible, the calculation of the strains, and a general sketch with details of the most important parts; weights of iron in the construction; total weight of superstructure; details as regards the history of the construction, name of maker, &c.; character of the materials, and results of experiments as to strength; amount of deflection under moving and fixed load, &c.

An example is given of an entry in the Bridge-Book, with a sketch referring to the Werda bridge, a double-line structure of six 67-feet spans.

D. G.

The Ventilation of the St. Gothard Tunnel.

Epitome of a Report by Dr. STAPFF, Geologist of the Company.

(Giornale del Genio Civile, Sept.–Oct. 1882, p. 549.)

In the number of the "Giornale del Genio Civile" for January 1880 appeared a paper upon Dr. Stapff's report upon the temperature of the rock in the St. Gothard tunnel. The present paper is an abstract of his report for 1881, which appeared in the last quarterly report of the Swiss Federal Council, and which deals with the temperature, humidity and ventilation, after the completion of the heading, and during the works for widening and lining the tunnel, and also with the rules which (founded upon the numerous observations taken during that time) show what currents of air may be anticipated in the working.

Temperature.—The currents of air at the entrances lower the temperature only through a portion of each half of the tunnel, while towards the central portion they have the effect of raising it. The southern end is generally warmer than the northern, owing to the external air being warmer at the south. The following figures show the gradual and absolute cooling throughout the tunnel. During the driving of the heading the mean temperature of the rock was 23°·43 Centigrade; on February 29th, 1880, after the heading was complete, the temperature of the air was 21°·69 Centigrade; on February 11th, 1881, it was 19°·30

Centigrade; and on February 24th, 1882, it was 14°·15 Centigrade.

Humidity of the Air.—This, which has such an injurious effect on the workmen, is gradually diminishing, but is still considerable, particularly at the southern end.

Ventilation.—The natural ventilation depends upon the difference of the atmospheric pressure at the two ends, the temperature and the moisture. The current comes from the end at which the pressure is the greater, and its velocity increases with the square root of the difference of the pressures. The difference in level between the two ends (118 feet) increases or diminishes the velocity of the current according as the internal air is lighter or heavier than the external, and as the current comes from the north or from the south, or *vice versâ*. The augmentation of volume of the air which enters the tunnel and becomes warmer interferes with the circulation, as also does friction.

If v represents the velocity of the air in metres per second; d' and d'' the weights of a cubic foot of air at the northern and southern ends; μ a coefficient depending upon the resistance due to friction;

$$v = \mu\, 281 \cdot 8 \sqrt{d' - d'' + 0 \cdot 00032} \text{ for currents from the north;}$$

$$v = \mu\, 281 \cdot 8 \sqrt{d' - d'' - 0 \cdot 00032} \text{ for those from the south.}$$

The figure 0·00032 is due to the difference in density of the air at the centre of the tunnel and that outside at the two ends. It is the mean of ten observations, and diminishes with the gradual cooling of the tunnel. The density of the air is calculated by the formula $d = \dfrac{0 \cdot 00171 \times b}{1 + 0 \cdot 00367\, t}$ where t is the temperature and b the height of the barometer at the centre of the entrance. The value of μ has been ascertained to be 0·0796 by means of a series of experiments, during which it was found that the passage of trains seriously affected it.

The Author then proceeds to show that very slight atmospheric differences at the two ends suffice to alter the direction of the currents through the tunnel, and he gives tables showing from observation and calculation what would have been the direction and velocity of the current at different times throughout the year 1881 had the tunnel been complete, and from these tables he concludes that in that case the maximum velocities would have been from 10·85 feet to 14·27 feet per second, or a mean of 12·30, and the minimum velocities (after deducting the changes in direction) from 0·00 to 4 feet, or a mean of 2 feet per second.

If the question of ventilation could be decided by averages it would be seen that even in the worst case there would be a current of 4 feet per second, which would clear the tunnel of smoke (if no trains were running) in three and a quarter hours, so that, to ensure complete ventilation, it would only be necessary so to time

the trains that there would be once in every twenty-four hours an interval of three and a quarter hours between them.

Unfortunately, however, at each change in the direction of the current there is a period when the air is at rest, and though generally these changes of direction occur only at intervals of several days, and do not seriously interfere with the ventilation, there are times when they occur at such frequent intervals, that it may be anticipated that the current may be arrested for four days at a time; and here the question of the necessity of artificial ventilation arises. The Author gives the number of trains passing through daily, the amount of coal and of oxygen consumed, and of carbonic acid and carbonic oxide produced, the cubic capacity of the tunnel, and the percentage of noxious gases which would be contained in the air after four days' working with no natural current, and he concludes that the air would by that time be insupportable. He thinks, however, that such a state of things could not occur more than once a year, and might be avoided altogether by stopping some of the luggage trains at such times. He considers that it would be foolish to provide a costly method of artificial ventilation, which would be absolutely useless except upon these rare occasions. He is, however, of opinion that compressed air should always be available for the benefit of the workmen by means of cocks placed at intervals upon pipes running through the tunnel, and that a supply of drinking water should also be provided. The editor adds in a note that steps have been taken to provide air and water for the workmen.

W. H. T.

On the best Method of rapidly constructing long Tunnels.

By G. Bridel.

(Lucerne, 1883.[1])

The facts from which the Author draws his deductions relate principally to the Mont Cenis, St. Gothard, and Arlberg tunnels, a comparison being made between the modes of tunnelling adopted, divisible into two systems, viz., first, that of driving the advance-heading near the level of the roof of the intended tunnel; and secondly, where it is driven at the invert-level. The comparative merits of these two methods are reviewed, as regards speed of execution, suitability under various conditions, and economy.

In the St. Gothard tunnel, where the first-mentioned or "crown-heading" (Belgian) system was adopted, the piercing was effected in much less time than in the case of the Mont Cenis, where the advance-heading was driven at the low level, or on what may be

[1] The original is in the Library of the Institution C.E.

termed the "base-heading" (English) system. This advantage, however, was neutralised by the fact, that after this stage had been attained the completion of the Mont Cenis tunnel was effected in nine months, as compared with twenty-two months in case of the St. Gothard.

The Author attributes this discrepancy to the facilities afforded by the "base-heading" system, in the subsequent excavation and transport, and the non-necessity for the frequent shifting of the temporary running-road and the air-conduits.

At the Arlberg tunnel, commenced about two years ago, the base-heading system has been adopted, with the result that although the rate of advance of the heading is 50 per cent. more than that attained at the St. Gothard, the completion of the tunnel section follows as close upon the heading as was the case at Mont Cenis.

The mode of procedure in this instance was to excavate a series of vertical shafts (about 3 chains apart) from the roof of the heading upwards, until reaching the level of the crown of the intended arch; the upper portion of these shafts was then widened out, the excavation being shot, as through a funnel, into the wagons on the base-heading track.

On the 31st December, 1881, the east heading of this tunnel had been driven for a distance of 2,031 yards, and the length of the finished tunnel was 1,170 yards, or 861 yards in arrear of the former. In July 1882 the lengths of completed tunnel and heading were 2,544 and 3,288 yards respectively, the difference being 744 yards, or 117 yards less than six months previously. At the west end the amount of arrear was slightly greater, due to the bad character of the ground traversed. This difference, however, is being lessened, and the base-heading system is considered to have been thoroughly successful.

A diagram showing the order in which the various portions of the tunnel area are excavated is given. The ventilation was effected by a special set of air-pipes (independent of their supplying the boring machinery) varying from 1 foot 3¾ inches to 1 foot 7¾ inches diameter in the finished portion of the tunnel, and reduced to 1 foot where the work was proceeding. The air was delivered at a pressure of 3 lbs. per square inch.

The base-heading system was adopted at the Mont Cenis, and at first worked in the same manner as the above-described (Arlberg); but afterwards the excavation from above the advance-heading was worked out in two cores, from the face instead of by shafts. This method necessitated the use of very strong timbering for the base heading (advance), but as the fissured nature of the rock would have made this requisite under any circumstances, no additional expense was entailed. Mention is made of the Laveno tunnel, where continuous base-and-crown headings, with occasional communicating-shafts, were pierced by mechanical boring throughout the length of the tunnel, the excavation being removed through the lower heading. The tunnel was 3,210 yards

long, and was constructed in sixteen and a half months. This last method is recommended where the motive power sufficient for actuating the additional boring-machinery is obtainable.

The crown-heading system is then considered. The adoption of this system at the St. Gothard was principally due to the contractor, who, having his choice, preferred working on a system to which he had been accustomed. It was also hoped that with a crown-heading a better ventilation for the workmen would be procurable than had been the case in the Mont Cenis tunnel.

The advance-heading is followed by the removal of the excavation on each side, and as soon as springing-level is reached, the arch is constructed, and progressively underpinned with timber, permitting the erection of the side walls one at a time. The temporary way is first laid in the crown-heading, and as the various tiers of excavation below this are removed, the difference of level between each tier is surmounted by inclined planes of timber framing. Hydraulic elevators were introduced, but had to be abandoned on account of their being affected by the gases of the tunnel. A diagram shows the order in which the various cores of excavation are removed, and another compares the length of tunnelling under construction (Chantiers), at one and the same time, in the St. Gothard and the Arlberg tunnels. The distance from the completed portion to the heading of advance (crown-heading system) is in the former instance 3,007 yards, whereas in the Arlberg tunnel it is reduced to 1,258 yards.

A third diagram shows the progress of the excavation of the headings and the various cores, and of the masonry from end to end of the St. Gothard tunnel.

From this it is seen that the progress of the arch is irregular, and is accounted for by the desire on the part of the contractor to avoid expense, sought to be attained by shifting as seldom as possible the inclined planes connecting the tiers of excavation, stretching from the face of the advance heading to the formation-level at the finished tunnel. The Author, after estimating the lengths occupied by the various processes of excavation, of blasting, and the inclined planes, &c., concludes that the normal length of tunnel under construction (Chantiers), at one and the same time, with this system, cannot be less than 2,586 yards, and that the crown-heading is not suitable for cases where mechanical boring is resorted to and expedition of importance.

The most suitable system to be adopted in passing through ground exerting great pressure is considered, whether by constructing the arch first and then the side walls, or the reverse. When the arch is constructed first, allowances should be made for its settlement, as, however carefully it may be underpinned, in ground of this character subsidence and an inward movement of the springing is almost certain to ensue as soon as the whole excavation of the tunnel section has been removed. An instance is mentioned where the allowance for settlement was as much as 3 feet 3 inches in the "windy stretch" of the St. Gothard, and of

the difficulties encountered and distortions of the arching which occurred in the Foggia-Naples tunnel, where the ground was of a plastic nature; the opinion being that under such circumstances the Belgian method of constructing the arch prior to the side walls should not be attempted.

The cost of excavation to the full section of a tunnel constructed by means of the crown-heading, where the boring is done entirely by hand-labour, is 10 per cent. less than the same work where the base-heading is adopted; but when mechanical boring is resorted to, the saving in this item is reduced to 1·82 per cent. The cost of transport, however, is less with the base-heading system, and, as before mentioned, it is not necessary to shift the temporary track and the air-conduits, as is so frequently requisite in the crown-heading system; also the drainage is much better under control. A diagram shows the number of changes of the temporary track (including turn-outs and lie-byes), air-pipes, &c., on 1 kilometre of the St. Gothard tunnel during the term of construction (thirty-nine months). The percentage of the total number of men employed in connection with these latter items is 10 per cent., and this expense is reduced to comparatively nil where the base-heading system is adopted.

In the St. Gothard tunnel, up to the time of the junction of the north and south headings, the ventilation was very imperfect; air was supplied to the length under progress by piercing the pipes conveying air at a pressure of 90 lbs. (six atmospheres) to the boring-machinery, but the motive power was insufficient to maintain a sufficient supply at that pressure, so that neither proper ventilation nor supply to the boring-apparatus was attained.

The contractor for the Arlberg tunnel was paid

	£.	s.	d.	
At the rate of	79	17	7	per lineal yard.
Interest on plant supplied by the company	17	5	0	,, ,,
	£97	2	7	

The contractor of the St. Gothard tunnel was paid

	£.	s.	d.	
At the rate of	133	4	3	per lineal yard.

The rock formation of the St. Gothard was harder than at the Arlberg.

In conclusion, the Author is of opinion that for tunnels required to be executed with rapidity, the method of base-heading is preferable to crown-heading.

D. G.

The Wilkau-Kirchberg Narrow-gauge Railway, in Saxony.

By Messrs. KÖPEKE, BURGMAN, and VON LILIENSTERN.

(Jahrbuch des Sächsischen Ingenieur und Architekten-Vereins, vol. i., p. 26.)

In a country so intersected by railways and so mountainous as Saxony, it can scarcely be a matter of surprise that many of the local lines, which are dependent on the traffic of the district for support, should be worked often at a loss, irrespective of the effects of the too rapid development by private enterprise of the railway system in 1870. After that date, great depression set in, which compelled the Government to purchase these lines for the sake of maintaining the traffic. Government itself also had embarked in not a few expensive and unprofitable projects, the cost of which has been a serious burden on the finances of the entire system of Government railways, so that it became absolutely necessary either to put a stop to all further construction by the State, or adopt a more simple and less expensive mode of construction. The last-named alternative was chosen.

Accordingly, in 1878 the Pirna-Berggiesshübel Railway (of which 15 kilometres were opened in 1880) was commenced as a standard-gauge line, and in 1880 a beginning was made with—(1) The standard-gauge branch line from Scharzenberg to Johann-georgenstadt (17 kilometres); (2) The narrow-gauge lines Wilkau-Kirchberg-Saupersdorf (10 kilometres), and Hainsberg-Dippoldiswalde-Schmiedeberg (21 kilometres).

The present Paper deals with the section Wilkau-Kirchberg, rather more than 4 miles in length, which was opened for traffic on the 17th October 1881.

Wilkau was originally merely one of the stations on the Zwickau-Schwarzenberg State Railway, opened for the benefit of the town of Kirchberg, which contains about six thousand inhabitants, and is the centre of a district containing about sixteen thousand souls, more or less interested in the production, manufacture, and dyeing of woollen goods. The gauge of the line is 0·75 metre (2 feet 6 inches). As shown on the plan, the line diverges from the Zwickau-Schwartzenberg State Railway opposite the Wilkau goods station, and at the end of the first kilometre it joins the highway, which it follows the whole way to Kirchberg, the road formation being utilized for the railway. The distances of all fixed structures are the same as those for the standard-gauge lines, to admit of the transport of bulky goods, &c. The section shows the maximum grade to be 1 in 40. The minimum radius for curves is 50 metres (164 feet); between Wilkau and Kirchberg, however, no curve under 70 metres radius occurs, but in the town of Kirchberg 50-metre curves are the rule. Of the 10 kilometres of line between Wilkau and Saupersdorf, 6·2 are on the straight, the remainder being curves. The width of formation at the level of the top of the sleepers is—on the straight, 1·75 metre (5 feet

9 inches), and on sharp curves of less than 150 metres radius, 16 inches wider. The depth of the ballast is 16 inches; the slopes are 1½ to 1, with side-ditches 16 inches wide at the bottom, and 20 inches deep. The total cost of the earthwork, including stations, scarcely exceeded £144 per mile.

Bridges, &c.—Near Kirchberg the river and the mill-stream are both twice spanned by iron-girder bridges, the rails being laid directly upon the girders. The river-bridges consist of a continuous girder, spanning two openings, one 40 feet, the other 56 feet in width, and cost about £450 each; those over the mill-stream cost £100 and £200 respectively; the remaining culverts, &c., cost in all £300; making a total for bridging of £1,500, or £340 per mile.

Permanent Way.—This is of the ordinary type, with transverse sleepers, and differs from that of the standard gauge only in the dimensions being less; 5,720 lbs. per wheel was the load on which all calculations are based. It cost about 8*s.* 9*d.* per yard, or, including the cost of ballasting, laying, packing, &c., 12*s.* per yard.

Level Crossings are numerous, especially on the highway, there being neither over- nor under-bridges on the line. The cost was £335.

There are three stations:—(1) The junction at Wilkau, where extensive alterations in the original station have been made to connect the narrow-gauge line with the existing passenger and goods platforms, in order to avoid any new buildings. There are 1,038 yards of sidings, eleven switches, and five cross-over roads. (2) Cunnersdorf, an ordinary roadside station. (3) Kirchberg, where, compared with the traffic received, the accommodation is small; but all the principal factories, fifteen in number, are to be connected by sidings with the main line. Two river diversions, costing £50 and £75 respectively, were made. Compensation for the portion of the road occupied, &c., was paid at the rate of £259 per mile.

Fencing and Signals are entirely dispensed with, the only signal in existence being that at Wilkau. A telegraph line, however, has been erected on the State telegraph posts for future use; meanwhile it serves as a means of communication between the two terminal stations.

A statement of the total cost of the line cannot be given; the following is a summary of the items already mentioned:—

	£
Section Wilkau-Kirchberg (4·16 miles) = . .	23,400
„ through the town of Kirchberg = . .	8,550
Total	£31,950

The traffic is under Government supervision. Tickets are issued in the train; there are only second- and third-class carriages. The rates are calculated in the same way as on the main lines; no charge for transhipment is made. The line has not yet been

carried through the town of Kirchberg, nor have the different factories been connected with it; still the traffic is brisk, and affords an encouraging prospect of what it will be when the scheme is fully developed.

W. A. B.

The Grosswardein Steam-Tramway. By Jos. Porges.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, vol. xxxiv., 1882, p. 127.)

This tramway, which was opened for traffic in August 1882, was designed with the view of connecting the different factories and mills in Veleneze and Varalja with the eastern branch of the Hungarian State Railway. It forms a junction with the railway at a point about two miles from the principal station, Grosswardein.

The tramway is generally laid along the side of the streets, with the centre line at least 3·45 metres (11·3 feet) from the face of the nearest houses; only in two streets, varying in width from 25 to 30 feet, is the line laid along the centre. The hidden position of many of the factories which the line feeds, and the irregular course of the streets made the line a very tortuous one, and involved the introduction of a great number of sharp curves. The minimum radius allowed was 80 metres (262·5 feet) in the factory yards, and 100 metres (328 feet) in the streets of the town. The steepest gradient on the line is 1 in 100.

For the formation of the road, in most cases, a trench of rectangular cross-section 8½ feet in width, and 9 inches in depth, is dug along the centre line; the bottom of the trench is covered with about 4 inches of ballast, on top of which the permanent way is laid. The sleepers are covered to rail level with gravel which, on the outside of the rails, is sloped off gradually to the road-surface.

In the cases where the line is laid along the side of the street a paved gutter separates the tramway from the footpath.

The only portions of the line which are paved are the intersection of roads, and a length of 160 yards in one of the most important streets. Where the roads had to be raised the slopes between them at the footpaths were stone paved, and in one case the construction of 70 yards of retaining wall was necessitated.

The permanent way consists of old rails of the Vignoles' pattern, weighing 71·5 lbs. per yard, on oak cross-sleepers 7·2 feet in length, 5 inches in thickness, and 3 inches in breadth at the top, increasing to 9 inches at the bottom. To the sleepers are attached continuous wooden guards 2 inches from the edge of the rail; on curves this distance is increased to 3 inches. The space between the rail and the guard is filled up with concrete to within 1·3 inch of the top of the rail. The angle adopted for the

crossings, which are of chilled iron, is 6° 20′. Each factory yard is provided with a turntable 13·1 feet in diameter.

To enable the line to run into a large oil- and starch-factory a considerable piece of land, lying immediately about it, had to be purchased by the company. On this land, workshops and the necessary residences for the accommodation of the hands employed on the line were erected.

As the trucks, in which goods are forwarded to the different factories, are the property of the railway, only a small number is required for the tramway. These are furnished with powerful brakes, and when filled with ballast, serve as brake-vans to those trains which are not provided with a sufficient amount of brake-power.

The line is worked by two 60-HP. Krauss engines. In these the foot-plate is placed, not as usually at the back of the engine, but at the side; this enables a better look-out to be kept. Subjoined is a list of the leading dimensions of these engines:—

Weight 10,600 kilograms		10 tons.
„ (loaded) 13,000 kilograms.		12·8 „
Capacity of tanks	2·0 cubic metres	2·6 cubic yards.
„ „ bunkers	0·5 „	0·6 „ „
Length over all	5·3 metres	17·4 feet.
Breadth „	2·3 „	7·5 „
Wheel-base over all	1·6 „	5·3 „
Diameter of wheels	0·8 „	2·6 „
Steam-pressure, 12 atmospheres		173 lbs.
Diameter of cylinders	0·225 metre	8·9 inches.
Stroke of piston	0·4 „	1·3 foot.
Total heating-surface	23·6 sq. metres	254 sq. feet.
Effective tractive force	1,518 kilograms	3,347 lbs.
Speed per hour	11·8 kilograms	7 miles.

The cost of one of these engines was £920.

J. R. B.

The Wülfel-Döhren Tramway with Heusinger von Waldegg's patent Permanent Way.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xix., 1882, p. 260.)

This tramway was built for the purpose of supplying material to a wool-washing and combing establishment in Döhren, a small village on the outskirts of Hanover; it connects Döhren with the nearest railway station, Wülfel, on the Hanover and Cassel Railway, and is just under 3 miles in length; it was begun early in the winter of 1881, and completed in March 1882. In 1881 the number of loads of wool which were deposited at the establishment amounted to four hundred; besides this, four hundred and fifty loads of coal were consumed.

As the business of the Wool-washing and Combing Company was rapidly increasing, it was decided to lay down a metre-gauge

tramway to Wülfel. The 4 feet 8½ inches gauge, which would otherwise have been the most convenient, could not be adopted on account of the value of the property through which the line passes, and of the sharp curves of which it to a great extent consists. In order to render unloading and reloading the wool at the railway station unnecessary, the railway company's trucks, together with their load of wool, are placed on low frames mounted on two four-wheeled bogies.

The line is laid partly across country, and partly along the main road to Hanover. Its sharpest curve has a radius of 105 feet, and nine have radii varying from 148 to 164 feet. The general fall of the line is in the direction of the works, and the steepest gradient is 1 in 70. A truck-load in the down-train weighs from 10 to 15 tons; whilst the up-train trucks loaded with washed and combed wool, do not carry more than 3 tons 15 cwt. per truck, and coal is, of course, only carried by the down trains. At the works at Döhren there is one turntable, of the simplest construction, with eight lines of way radiating from it, thus obviating the necessity of points and switches. The line was originally worked by horses, but the traffic having increased to two hundred and forty wagons per month, it was decided to supersede their use by that of locomotives.

The rails are rolled in two sections, which are afterwards connected by rivets placed at intervals along the common neutral axis, and in such a manner that one end of each section projects about half a yard beyond that of the other. The projecting ends of two consecutive rails, which thus fish each other, are connected by a couple of ¾-inch bolts placed about a foot apart. One of the sections forms the actual rail, whilst the other serves as a check rail. The lower flanges of both sections form a common trough-shaped longitudinal sleeper, under which the ballast is tightly packed. At intervals of about 10 feet, tie-bars of rectangular or ⊥ section are placed, and connected to the lower inside flanges of the rails by a wedge and a couple of rivets. The weight of this permanent way is 100 lbs. per lineal yard.

J. R. B.

Lyons, Fourvière, and St. Just Wire-rope Railway.

By F. Grivet.

(Revue Générale des Chemins de Fer, 1882, pp. 77 and 163.)

The industrial portion of the city of Lyons, situated in the plain near the junction of the rivers Rhône and Saône, is dominated on the north and west at a considerably higher level by the suburbs of Croix-Rousse, Fourvière, and St. Just respectively.

The difficulty of access to these districts for the working classes, who are chiefly employed in factories situated at the low-level, led to the construction of a rope-railway in 1863, connecting the

city with Croix-Rousse, which lies at an elevation of 230 feet (70 metres) above the plain. This enterprise proved a perfect success, and was followed by the commencement, in 1878, of the railway described by the Author. The population of the suburb of Fourvière and St. Just was at that time sixteen thousand, to which might be added, in estimating the probable traffic, a large number of visitors, pilgrims, &c., to the church of St. Fourvière and the cemetery of Loyasse, the fare to be charged being the same as on the existing Croix-Rousse line, viz., 1*d*. The length of the railway is 900 yards, there being, in addition to the terminal stations, a third one (Minimes) situated exactly midway, but not at mid-level. The difference in level of the terminals is 320·3 feet (97·62 metres), but the gradient below the Minimes station is much steeper than that on the upper half of the line, the altitudes surmounted being 238 feet and 82·3 feet respectively. The railway is laid with a double line of 4 feet 11 inches (1·5 metre) gauge, and runs in tunnel for about four-fifths of its length, it being in the open for a short distance at each of the stations. The tunnel is 26 feet 3 inches wide, 16 feet 6 inches high at soffit of the arch, which is semi-circular, and giving a headway of 13 feet 8 inches over the outside rail of each track. The rails are of the Vignoles section, weighing 74½ lbs. per yard, rolled, as a rule, in 30-feet (9 metres) lengths, so as to diminish the number of joints, the character of brake adopted precluding the use of fish-plates. The rails are fixed on longitudinal balks of pine, 9½ inches × 7 inches in section, attached to and resting on oak cross-sleepers 8¾ inches × 6 inches, placed 5 feet 9 inches apart, this distance being reduced to 3 feet 3 inches at the joints.

The method of working the traffic is by an endless wire-rope, carried on rollers and passing around a drum driven by a stationary engine at the summit. The difference in degree of the gradients on the upper and lower halves of the line lead to unequal strains being brought on the motive power, which are partly met by the special arrangements hereafter described. The gradient of the lower incline is 1 in 5, and that of the upper 1 in 16½, and the speed of the trains 13 feet per second. The dead-weight of the train is about 17 tons, which, together with the weight of the wire rope, would require tractive forces of 8,666 lbs. and 2,305 lbs. per metre (3·28 feet) per second upon the lower and upper inclines respectively, or a difference of 6,361 lbs. per metre per second, equal to 152 HP., added to which, in some instances, would be the difference in power required in the case of the ascending train being loaded and the descending one empty. To neutralise this, two weighted wagons, termed compensators, are used in the following manner:—The starting of the engine causes one train, say No. 1, to leave the low-level station on the up-line and ascend the steep incline, at the same time that train No. 2 leaves the summit station and descends the gentle incline on the down-line. Train No. 2 is connected by a special wire rope (in length 450 yards, or equal to half the length of the railway) with a compensating wagon

(which only runs over the steep or lower incline, and is disconnected from the train on the ascending journey on arrival of the compensator at the Minimes station). Train No. 2, in its descent of the upper incline, at the same time allows of the descent of the compensator over the lower or steep incline, they being connected by the before-mentioned rope. The weight of the compensator is such as to equal, when descending the steep incline, the dead-weight of the train ascending the gentle incline; or the weight of the compensator *plus* the train, in their descent on the down-line, is about balanced by the resistance offered by train No. 1 in its ascent of the lower or steep incline on the up-line. Trains No. 1 and 2 arrive simultaneously at the Minimes or mid-way station; here the latter is detached from the rope previously connecting it with its compensator (now at rest at the foot of the steep incline), this rope being in the meantime kept taut by a counterpoise weight suspended in a well, 16 feet 6 inches deep, at the Minimes station. When train No. 1 commences its ascent of the gentle incline it is attached to the rope connected with its compensator (until now at the foot of the steep incline), and which latter consequently arrives at the Minimes station at the same moment that the train reaches its journey's end at the summit. In the case of the ascending and descending trains being equally freighted, the amount of work required to be done by the engine would vary from the power necessary for the traction of the nett load up the steep incline to the same load *plus* the difference between the tractive force exerted by a train descending the steep incline, as against the resistance of the compensator ascending the steep incline and the nett load up the gentle incline (neglecting friction). These conditions would of course change with variations in the freighting.

Details are given of the variations in the tractive force required to meet various conditions of loading, which, notwithstanding the compensating arrangement, are considerable.

The usual speed, as before stated, is 13 feet per second, which, with an allowance of one minute's wait at each of the three stations, allows about 7 minutes for each journey. The stationary engine is of 110 HP., but capable of working up to 240 HP. There are two cylinders, each of 1 foot $9\frac{1}{2}$ inches diameter and 3 feet $3\frac{3}{8}$ inches stroke, actuating the winding drum, which is 19 feet 8 inches diameter. The boilers are three in number, working up to 90 lbs. per square inch, with 2,582 feet of heating surface.

The rolling-stock comprises two passenger-carriages, each for one hundred passengers, two goods trucks (sufficiently large to carry a loaded wagon and two horses), and two compensators; which amount makes up the two trains.

There are two kinds of brakes in use, both working simultaneously and automatically, but also under the control of the guard. The one acts against the wheel (insufficient of itself to arrest a train upon a gradient exceeding 1 in $8 \cdot 3$); and the other, which is the

more powerful, and of which there is a pair fitted to each carriage, consists of a pair of metal disks of about 1 foot 8 inches diameter, the normal distance between is slightly in excess of the breadth of the rail-head.

When the train is under traction, these disks are maintained in a vertical position at a slight height above the rail; but should the traction-rope break, the pressure of a powerful spring comes into action and forces the disks down on the rail, whereupon the friction causes them to rotate, and at the same time to approach one another until firmly gripping the sides of the rail. Accidents have occurred by the fracture of the hauling-ropes, &c., of which the details are given, whereby the efficiency of these brakes has been tested.

A Table of brake-experiments, and another of particulars relating to the various cables in use since the opening of the line, are given. The first cable was manufactured at Belfort of Martin steel, but all since that have been obtained at Birmingham, of steel made from Swedish iron. The latest hauling-cable mentioned in the list weighs 12·94 lbs. per yard, or a total weight of 6·3 tons; has a diameter of $1\frac{3}{4}$ inch, and is made up of eight strands of nineteen wires each, surrounding a hempen core. The breaking-strain was 89·3 tons. Each of the wire ropes for connecting the trains with their compensators are $1\frac{7}{16}$ inch diameter, made up of six strands of nineteen wires, and weighs 8·85 lbs. per yard, or a total weight for each of about 2 tons.[1]

Details of cost are given, of which the following is a summary:—

		£.	s.	d.
Permanent way, 1,821 lineal yards (single line) at £1 16s. 7½d.		3,334	2	6
Ballast (Rhône gravel), 2,551 cubic yards „ 3s. 0¾d.		389	9	5
Engine, boilers, and winding-drum		4,920	0	0
Engine bed-plate and foundations for engines and boilers .		734	13	6
Chimney-shaft, water-tanks and conduits, &c.		450	16	2
Rolling-stock, comprising 2 passenger-carriages, 2 goods-vans, and 2 compensators		2,528	19	5
Main cable (steel), 1,083 lineal yards, 126 cwt., at £2 14s. 10½d.	£345 14s. 4d.			
Connecting-ropes (iron),[1] 974 lineal yards, 78 cwt., at £1 9s. 4d.	£114 8s. 8d.	460	3	0
Telegraph, gas, lighting, &c.		545	8	0
Total, omitting general expenses, interest, repairs, &c. . .		£13,363	12	6

Trains run sixteen hours daily in summer, and fourteen in winter; the number of journeys in each direction varying from ninety-six to one hundred and ten.

A Table of expenditure and receipts for 1881 is given, and the Paper is accompanied by diagrams of the works, and details of carriages, brakes, cables, &c.

D. G.

[1] These ropes (connecting train and compensator) are described in the Table as of steel, but in the summary as of iron.—D. G.

On the Comparative Estimation of Steam-Engines.

By Georg Schimming.

(Der Civilingenieur, 1882, p. 417.)

In this Paper the Author considers the general principles which underlie a rational investigation into the efficiency of steam-engines, with a view of obtaining their comparative value.

The Author remarks that the results obtained from the numerous engine-tests which have been made, have as yet not been commensurate with the labour expended on them, and that this arises from the fact that the quantities observed have often not been sufficient to allow of a definite estimate being formed, and that there is a great deal of obscurity as to what ought to be measured. The present Paper is intended as a contribution to the introduction of more rational methods of observation than those hitherto followed.

The Author considers that the only satisfactory unit of comparison for steam-engines is the quotient obtained by dividing the work done by the heat supplied, *i.e.*, the number of units of heat supplied to the cylinder per hour per effective HP.

The Author discusses the various ways in which the initial heat is absorbed or lost, and, as a result of the principles laid down, suggests a draft form of Table to be filled up for any particular engine.

The Table should show :—

A. The external conditions.—1. Temperature of the condensing water. 2. Height of surface of same above the engine-room floor. 3. Height of barometer.

A_1. Conditions intermediate between A and B.—1. Height of discharge from hot-well. 2. Temperature of engine-house.

B. Conditions which are a function of the construction.—1. Double- or single-acting engine. 2. Compound or not. 3. Ratio of cylinder to receiver. 4. Continuous action or pauses. 5. Amount of contained moisture. 6. Pressure of steam at stop-valve. 7. Ratio of stroke to diameter of cylinder. 8. Ratio of surface of clearance to that of cylinder. 9. Temperature of exhaust-steam and mean back-pressure. 10. External cylinder surface in square inches per available HP. 11. Ratio of surface of piston-rod to internal surface of cylinder. 12. Vacuum.

B_1. Conditions intermediate between B and C.—1. Temperature of condensing-water. 2. Compression. 3. Cut-off in large cylinder.

C. Variables.—1. Expansion. 2. Revolutions. 3. Use of steam-jacket. 4. Amount of throttling (pressure-difference before and after stop-valve).

D. The result of A B C, viz., the units of heat per effective HP. per hour. For the calculation of D the necessary data are—

E. The loss by cooling, internal and external.

F. The loss by back-pressure.

G. The work required to drive the engine itself.

To each of the losses, E F G, should be appended its immediate result, viz., E_0 the total, F_0 the indicated, and H the effective HP. The available power D_0 is calculated from E_0 and E. The losses under E F G should be given in percentages of D_0, E, F_0.

W. P.

On Indicators of the Watt type. By L. DE MAUPEOU.

(Mémorial du Génie Maritime, 1882, p. 143.)

The Author first gives a short account of the principles and action of indicators of the above class, noting the modification introduced by Mr. Kenyon of a pistonless indicator. He first gives, in a classified Table, the dimensions and particulars of the principal indicators in use, including those of Garnier, Cody, Richard, Martin, Darke, Deprez, and Kenyon, and then discusses their relative advantages under the three following heads:—

(1) The movement of the pencil;
(2) The movement of the paper;
(3) The results of actual experiments.

(1) The chief points to be considered under the first head are: the mode of carrying the pencil, or marker; the verification of the spring; the influence of friction; vibrations and their causes, including the laws of vibratory movement and means employed to reduce the vibrations.

Concerning the mode of carrying the pencil, the chief improvement introduced has been the employment of parallel motion to amplify that of the pencil. This has been very successfully done in the Richard indicator, and others, though more elaborate, scarcely act so well. The most difficult, but most essential, condition is, that the position of the pencil shall always correspond exactly with the pressure of steam. This necessitates (1) That the spring be properly constructed; (2) That the apparatus be not influenced by friction, play of the joints, or other disturbing causes; (3) That the indications may not be falsified by inertia of pieces, vibrations of the spring, &c.

Some remarks are made concerning the verification of the spring, in connection with which a Table of experiments is given, and also curves showing results of tests of the Kenyon indicator, both when it was in a heated and in a cold state.

The influence of the friction of the pencil is not always injurious, a moderate amount, in some cases, being proved to be beneficial. In the cylinder, however, the friction should be as small as possible, and when it is considerable, a series of steps in the diagram is shown to result.

The principal cause of deformation of the diagram arises from the vibration of the spring and of the movable parts of the instrument. It is shown that, assuming the pressure to act suddenly

upon the piston of the indicator, and neglecting the influence of friction, &c., the piston should pass the position of rest to a height equal to that which it travelled from the admission of steam. The causes which reduce the height of initial oscillation are of two kinds :—

(1) The effect of steam upon the piston is not instantaneous.

(2) All the causes of loss of kinetic energy, as friction of the piston and of the pencil, heating of the spring, shocks in the joints, &c., concur to reduce the oscillation.

An investigation of the laws of vibratory movement of the spring shows that the expression for the time of its oscillation is of the same form as that for the motion of a pendulum. The Author concludes from the reasoning which he gives, that the time may be taken as sensibly independent of the amplitude, as well as of friction; in which case it is

$$t = \pi \sqrt{\frac{m\,e}{s^2}},$$

where m = mass of the piston, &c.,

s^2 = area of the piston,

e = scale of the spring, or movement, corresponding to pressure of unity.

Friction probably diminishes this value slightly. Various means of reducing vibrations have been adopted: by diminishing the mass of the moving-pieces and the scale of the spring; by throttling the steam, as in the indicators of Deprez and Martin; while in the old indicators this was effected by the adroit (!) workman, who checked the vibrations by placing his finger at the right time upon the piston-rod of the instrument.

(2) The various well-known means of obtaining the motion of the paper are described. One not perhaps so well known, but ingenious, is to have an arm rigidly connected with the piston-rod of the engine, and moving to and fro with it; this fits on both sides of a twisted plate, which forms a screw of very large pitch. The screw has its axis in a line with the cylinder on which the paper is wound, and thus communicates the necessary motion to it.

Finally, numerous diagrams from the various indicators are given.

The Author's conclusions are: that though the Richard indicator marked considerable progress, yet, taking all things into account, the instrument of Martin is the most satisfactory for general purposes. Neither the indicator of Deprez, nor that of Kenyon, have yet arrived at a sufficiently improved form to meet all the exigencies of the every-day work of a dockyard.

H. S. H. S.

The Herreshoff Vedette Boats. By B. F. Isherwood.

(Report made to the Bureau of Steam Engineering, Navy Department, U.S., August 9, 1882.)

The "Herreshoff Manufacturing Company," Narragansett, constructed vedette boats, of identical pattern, for the French Government and for the British Admiralty. The results of trials of these boats, partly witnessed by Mr. Isherwood, form the subject of his official report.

The hull is of wood, uncoppered, having frames of white oak $1\frac{3}{8}$ inch square at 12-inch centres; and pine planking in two courses, of which the inner course, $\frac{3}{8}$ inch thick, is laid at an angle of 45°, and the outer course, $\frac{1}{2}$ inch thick, horizontally. The deck planks, $\frac{3}{4}$ inch thick, are of mahogany. The length of the hull is 48 feet extreme, and 46 feet at the water-line; it is 8 feet 10 inches wide extreme, and 7 feet 5 inches at the water-line, and it is 5 feet deep amidships. The draught forward, at rest, is 2 feet $5\frac{1}{2}$ inches, and aft 2 feet $6\frac{1}{2}$ inches, or with skeg, 3 feet $5\frac{1}{2}$ inches. The displacement is 260 cubic feet, with a maximum transverse section of 9·08 square feet, and $355\frac{1}{2}$ square feet of wetted surface. The hull is divided transversely by five water-tight bulkheads, and it weighs with fittings 6,933 lbs.

The engine is vertical, compound, condensing, and direct-acting, above the screw-shaft. The cylinders are 8 inches and 14 inches in diameter, with strokes of 9 inches. The air-pump, single-acting, worked by a lever from the second cylinder, is $4\frac{1}{2}$ inches in diameter, with a stroke of $3\frac{1}{8}$ inches. The feed-pump, similarly worked, is single-acting, having a $1\frac{1}{4}$-inch plunger and a stroke of $5\frac{1}{4}$ inches. The circulating-pump, double-acting, is $1\frac{1}{2}$ inch in diameter, with a stroke of $1\frac{1}{2}$ inch. The surface-condenser consists of two bent copper pipes, each 43 feet long, placed outside the vessel under water, one at each side. The pipes are $\frac{1}{32}$ inch thick, and are $3\frac{1}{2}$ inches in diameter inside at the receiving end, tapering to $1\frac{1}{4}$ inch at the delivery end. The area of condensing surface, externally, is 54·88 square feet. The crank-shaft is of steel, having four journals $2\frac{1}{2}$ inches in diameter.

The boiler is of the Herreshoff type,[1] circular. It is made of three coils of pipe, of which the inner coil is of a beehive form, resting on a circular wall of brick containing the fire-grate. This coil is surrounded by a cylindrical coil, resting also on the brick wall; and the second coil is capped by the third, a flat horizontal coil. The cylindrical coil is enclosed in a sheet-iron casing, connected with a conical up-take, which is made double and is filled with mineral wool. The chimney stands on the top of the up-take. The gaseous products of combustion pass off between

[1] A notice of the Herreshoff boiler was given in the Minutes of Proceedings Inst. C.E., vol. lxvi., p. 419.

the rings of the first coil into the interspace, and thence through the upper horizontal coil to the chimney. The feed-water from the hot-well enters the outer coil at the bottom, passing through it into the upper horizontal coil, thence into the inner or beehive coil, analogous to an ordinary fire-box, and passing from the bottom of it to an upright cylindrical receiver or separator, wherein the water of the mixture delivered from the boiler is separated from the steam by gravitation. The furnace is 4 feet in diameter, and the walls are 12¾ inches high. The outer cylindrical coil consists of seventeen rings of pipe 1·272 inch in diameter inside, turned on an imaginary cylinder 4 feet 4½ inches in diameter, and 2 feet 8¼ inches high. The upper horizontal coil is composed of ten rings of pipe 1·272 inch in diameter, and is 4 feet 4½ inches in diameter. The inner beehive coil is 46 inches in diameter at the base, and 29½ inches high inside. It is composed of pipes successively 1·272 inch, 1·494 inch, and 1·933 inch in diameter inside. The total length of piping composing the boiler is 477 feet, having 173·82 square feet of external heating-surface, or 136·23 feet of internal surface, and a capacity of 5·367 cubic feet. The chimney is 16½ inches in diameter, and is 13 feet high above the fire-grate. A fresh-water tank is stowed under the boiler as a reservoir for making up waste.

The furnace is worked by a forced draught of about 5 inches of water, for the production of which a blowing engine is employed, having a 2½-inch steam-cylinder with a 5-inch stroke, connected direct to a fan-blower 42 inches in diameter externally.

Three different screws have been employed for the propulsion of the vedette boats. They are all four-bladed, 35½ inches in diameter, of different pitches. They have a length of 0·4 of the pitch; the pitch is uniform, and the blades are at right angles to the shaft.

Screw A has a pitch of 3½ feet; screw B a pitch of 4·08 feet; and screw C a pitch of 4·42 feet.

Screw A was tested in Narragansett Bay in June 1881, when the vedette boat had a mean draught of 2 feet 11½ inches, in smooth water and calm air. With 95 lbs. steam in the boiler, cutting off in both cylinders at two-thirds of the stroke, making four hundred and fifteen revolutions per minute, the vessel made a speed of 13·53 miles per hour, with a slip of 18 per cent., for 95¼ IHP. In a second trial, with 35 lbs. steam in the boiler, a speed of 10·55 miles per hour was attained, with 13·5 per cent. of slip, for 28·73 IHP. In a third trial, with 19½ lbs. steam in the boiler, a speed of 7·70 miles per hour was made, with 12 per cent. slip of the screw, for 12·32 IHP. The distribution of the power, and the thrust of the screw were calculated by Mr. Isherwood to be as follows:—

Screw A.	1st Trial.		2nd Trial.		3rd Trial.	
	HP.	Per Cent.	HP.	Per Cent.	HP.	Per Cent.
Total indicated HP. .	95·242		28·732		12·317	
Power to work the engine	11·446		8·489		6·089	
Net power[1] . . .	83·756	100·00	20·243	100·00	6·228	100·00
Friction of the load .	6·282	7·50	1·518	7·50	0·467	7·50
Friction of water on screw blades . .	7·521	8·98	3·037	15·00	1·120	17·99
Slip of the screw . .	12·591	15·03	2·118	10·46	0·557	8·94
Propulsion of the vessel	57·362	68·49	13·570	67·04	4·084	65·57
Totals	83·756	100·00	20·243	100·00	6·228	100·00
	lbs.		lbs.		lbs.	
Thrust of the screw .	1589·3		482·24		198·89	

The trials of screw B, on a mean draught of 2 feet 11½ inches, were conducted with anthràcite, containing 17 per cent. of ash, and with Anzin briquettes, of washed bituminous coal and tar, containing 5 per cent. of ash. The averages of four runs with anthracite show that a steam pressure of 87·12 lbs. per square inch was maintained in the boiler; the engines made 380·27 revolutions per minute, and an average speed of 13·66 miles per hour was maintained. Against these results with anthracite, the results with briquettes as fuel showed that, whilst steam of 128·87 lbs. was maintained in the boiler, 463·17 revolutions were made per minute, and a speed of 16·34 miles per hour was reached. In an IHP. of 169·47, the slip of the screw was 20·33 per cent. These results place in a very clear light the relative merits of the two fuels.

With screw C the runs were made at Stokes Bay, in smooth water and calm air; mean draught, 2 feet 11½ inches; best Welsh coal used. Steam of 145 lbs. pressure was maintained in the first trial, 453·07 revolutions per minute were made, a speed of 17·43 miles per hour was kept up, with a slip of 23·39 per cent. In a second trial, a pressure of 93·2 lbs. was maintained, 76·63 IHP. was developed, with a speed of 12·64 miles per hour, and 24·40 per cent. of slip. In a strong wind and rough water, with a speed of 9·95 miles per hour, there was 27·47 per cent. of slip.

The sea-going qualities of the Vedette boats were excellent, and their performance in rough water was satisfactory. At the speed of 14 knots per hour, with the helm hard over, they turned in a circle of about 300 feet in diameter. When at maximum speed, they could be stopped in a few feet by backing the engine, and stern-way was acquired in the course of a few seconds. The vessel can go a distance of 90 knots, at a speed of 14 knots per hour,

[1] This power should be 83·795 HP., not 83·756 HP. as given in the report for the first trial.—D. K. C.

with her bunkers filled with the best steam-coal. The Herreshoff coil-boiler cannot be made to prime, and possesses a great degree of evaporative efficiency. Radiation of heat from the boiler is less than that of any other form of boiler. Briquettes could be burned at the rate of 168 lbs. per square foot of grate-area, for three hours, or 56 lbs. per hour. The pressure of air in the stoke-hole varied as the square of the speed of the blower. The maximum pressure that could be maintained was 4½ inches of water at 70° Fahrenheit, equivalent to a pressure of 0·162 lbs. per square inch, when the blower made 1,000 revolutions per minute.

D. K. C.

The Brayton Petroleum-Engine.

(American Machinist, No. 45, 1882.)

This article describes, by the aid of illustrations, the best and most recent form of petroleum-motor. The principle of its action has been recently discussed before the Institution.[1]

The engine itself, which in external appearance resembles an ordinary horizontal steam- or gas-engine, has a compressing-pump, or compressor, directly under the extremity of the crank-shaft from which it is driven. This pump compresses air into a reservoir, forming the bed of the engine, which is made of wrought iron, with steel ends, strongly riveted, and tested to 300 lbs. per square inch. The valve, which opens and closes communication between the reservoir and the single-acting cylinder, is worked by an adjustable cam on the vertical governor-spindle. Both this and the exhaust-valve, which is also worked by a cam, are of the ordinary conical form. A small pump, worked by an eccentric on the governor-spindle, forces oil into an annular groove packed with porous cotton braid. This groove surrounds the former valve, and is called an "evaporator," since from this the oil evaporates and mixes with the air from the reservoir. To start the engine a vent is removed, and a small jet of air sent through the evaporator; a few strokes of the pump are also made to inject a small quantity of oil. A plug, called a fire-stop, is then displaced, and a match applied to ignite the vapour. Combustion continues till the above-mentioned valve is opened, when the compressed air enters from the reservoir and forces more vapour into the combustion-chamber. The pressure is thus raised sufficiently to start and run the engine.

It is stated that although the ignition of the mixture (consisting of 1 part of vapour to 12 of air) causes the gases to expand about six volumes, there can be no increase of pressure, because of the communication between the reservoir and cylinder. The accom-

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[1] Minutes of Proceedings Inst. C.E., vol. lxix., pp. 231, 244.

panying diagrams, of which the scale is given, do not bear out this statement, the pressure in one being as much as 13·75 lbs. above the given maximum pressure of the reservoir.

Special arrangements have been made for removing the "bonnet," or back cylinder-cover, in order to clean the wire-gauze, through which the vapour and air passes, from carbonaceous deposit.

Not only the cylinder, but the bonnet, the compressor, and even the piston, have water-circulation.

The engine in question indicated 6·79 HP., after deducting 5·13 HP. for friction, and working the compressor. It is stated that 10 gallons of crude petroleum will develop 5 HP. for ten hours.

H. S. H. S.

Direct-working Pulsometer. By C. Ulrich.

(Journal für Gasbeleuchtung, 1882, p. 735.)

The purpose of the pulsometer is to raise liquids by utilising the expanding and contracting properties of steam in such a manner that these properties are brought to bear directly upon the liquids without the intervention of any mechanical arrangement. The pulsometer consists of two vessels, which are so constructed and fitted as to permit the steam and the liquid to enter each vessel alternately, and its working depends upon the internal thermal relationships. The steam acting in one of the vessels exerts pressure on the liquid in that vessel, and drives it out through the valve at the back. During this period the surface of the liquid assumes the temperature of the steam, and forms a piston, or buffer, between the cold liquid and the hot steam. When the vessel is emptied the steam passes into the outlet-pipe, and, the surface of the liquid being broken up, the steam mixes with it, and is rapidly condensed. In consequence of this a vacuum is formed, and the pressure in the opposite vessel being in excess, the ball of the steam-valve is driven over, closing the inlet to No. 1, and opening that to vessel No. 2. Whilst the steam is acting in one vessel the vacuum in the other is replaced by fresh liquid, which rises through the valve situated below.

In considering the action of the pulsometer, it is clear that, at the moment of condensation, the steam, relieved from the back-pressure of the water, rushes with full force into the vessel, and that, during the time occupied in reversing the valve, the steam passing into the vacuum is entirely lost, so far as useful effect is concerned. Owing to the velocity with which the steam rushes in during this period the loss from this cause is very great, and may be calculated as follows:—If it be required to raise 1,000 litres (220 gallons) to a height of 30 metres (98 feet) per minute, a quantity of steam equal to 6 cubic metres at 5 atmospheres pressure

$= 154 \cdot 44$ kilograms (340 lbs.) per hour will be required. Assuming that a pulsometer capable of performing this work makes sixty pulsations a minute, and that the reversal of the valve occupies one-fifth of a second, then a loss of steam equal to one-fifth of the weight of steam which can pass through the opening into the vessel in one hour must result. The steam-inlet in such an apparatus must have a diameter of 25 millimetres (0·97 inch); this gives an area of 625 square millimetres. Now it has been proved by careful experiment that 2·656 kilograms of steam at 5 atmospheres pressure will pass through a round hole 1 millimetre in diameter; therefore, through 625 square millimetres a quantity equal to 1,658 kilograms would pass, and the loss incurred by the change of valve will amount to $\frac{1,658}{5} = 331 \cdot 4$ kilos. (729·7 lbs.) per hour. The total quantity of steam used is therefore $331 \cdot 4 + 154 \cdot 44 = 458 \cdot 84$ kilograms per hour.

At the Berlin Exhibition of Manufactures, 1879, experiments were made by the Berlin District Association's engineer, which showed that a Hall pulsometer raised the temperature of the ascending fluid 2·2° Centigrade for 10 metres of height; and Mr. M. Neuhaus also states the increase to be 6° for 34 metres of height. If 0·2° per metre be taken as the average, the loss of steam in raising 1,000 litres 30 metres high is $\frac{1,000 \times 0 \cdot 2 \times 30}{640}$ $= 9 \cdot 37$ kilograms per minute, or 562·2 kilograms per hour. In practice, therefore, the consumption of steam exceeds the quantity stated above by 76·36 kilograms per hour.

To prevent so great a loss of steam is the object of the Author's invention. This is accomplished by a steam-valve, which changes the direction of the steam with greater rapidity. Instead of a ball-valve, a metal tongue or disk is used, which oscillates on a knife-edge, and lays itself against a faced surface on either side at each reversal. The steam is introduced at the top, over the valve-seats; and in the valve-chamber are constructed steam "sacks," which are closed by the valve simultaneously with the entrance to either side of the pulsometer. Steam is admitted to the "sacks" direct from the steam-pipe. When the pressure of steam in one vessel becomes reduced by condensation, the steam in the "sack" of the opposite vessel expands and thrusts over the valve. The steam thus employed then passes into the vessel now placed in communication with the steam-pipe, and is utilized in the work of pumping. If the working-pressure be 4 atmospheres a reduction by condensation to 3·4 atmospheres is sufficient to effect the change of the valve; the steam, therefore, never enters either vessel after the internal pressure is reduced below this point. The saving in steam is shown in practice to be considerable. Pulsometers of this description, at work at Mülhausen and at the brown-coal mines at Grunow, show that the temperature of the water is raised 0·109° Centigrade for each metre of height.

Taking the previous hypothetical case as an illustration, in which 1,000 litres are raised 30 metres high per minute, the result is—

$$\frac{1{,}000 \times 0 \cdot 109 \times 30 \times 60}{640} = 306 \text{ kilograms of steam per hour.}$$

The theoretical quantity required being, as shown, 154·44 kilograms, there are lost 141·56 kilograms, as against 331·4 kilograms by the ordinary pulsometer.

The Ulrich pulsometer is manufactured by Körting Brothers, of Hanover.

G. E. S.

On Brakes and Safety-Winches. By A. Ernst.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxvi., 1882, p. 504.)

In this Paper the Author describes some of the many inventions which have been made with the object of giving increased safety to the working of crabs, lifts, and other hoisting appliances.

Hoisting-gears, which are also intended for use in lowering loads, are usually supplied with a brake and a ratchet, and before lowering a load the brake must be pinned down, the ratchet-pawl disengaged, and the hoisting-pinion slid out of gear; neglect of these precautions has often resulted in bad accidents, caused by the handles flying round.

The first class of improvements described in the Paper deal only with the ratchet difficulty; they are all based on the brake described by Reuleaux as far back as 1868. In this the brake is loose on the shaft; during hoisting it is held fast by the brake-strap, and acts as a fixed point off which the ratchet can get a purchase. When the brake-band is slacked the load is lowered out, the brake and ratchet then running round together.

Inventions of the second class described go a step further, and are so arranged that the winch-handles are automatically thrown out of gear when the load is being lowered; in most of the arrangements a backward pressure on the handles disengages the hoisting-gear and controls the brake. In the most complete design a centrifugal brake is added, by means of which an acceleration of the descending load is entirely prevented. The Paper is accompanied by sketches of the different arrangements described, nearly all of which have been in successful use.

W. P.

Apparatus for Testing Lubricants. By Franz Zach.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xx., 1883, p. 11.)

The Author, after showing how the cost of lubricating locomotives and carriages on the Dux-Bodenbach and other railways has been reduced during the last four or five years, and how, at

the same time, the instances of heated bearings have decreased by the use of improved axle-boxes and the substitution of mineral for vegetable oils, draws attention to the immense importance of determining the quality of a lubricant before selecting it. He states that the cost of lubricants for locomotives and tenders in 1880 amounted,

	Marks.		£.
On the German railways, to	3,815,827	=	186,816
„ Austro-Hungarian, to	1,243,716	=	60,890
For carriages during the same year on the German Railways, to	1,105,090	=	54,103
On the Austro-Hungarian Railways, to .	568,062	=	27,811
Total	6,732,695	=	329,620

Several machines have been designed for testing lubricants; among the best of which are, that of R. Jahns,[1] that of the Paris and Lyons Railway,[2] and that of the Eastern Railway of France, exhibited at Paris in 1878.

The Author maintains that all these apparatus are too complicated and delicate, and too ponderous for practical use in factories and railway workshops. He describes a machine designed by Professor E. Willigk, of Prague, which has been in use for some years on the Dux-Bodenbach Railway; it is of very simple construction, and gives results sufficiently accurate for all practical purposes. It consists of a hollow steel cup fitting accurately into a similar one of gun-metal; the latter is attached to a vertical shaft which is rotated by means of belting and toothed wheels. Two uprights or columns support a cross-arm, which serves as a bearing for the shaft; above this is another arm to which the two uprights act as guides. In an eye, in the centre of this arm, is fitted the steel cup, which is pressed down into its gun-metal bearing by a weighted lever hinged to the top of one of the columns.

In testing the lubricant, a small quantity is poured into the gun-metal bearing, the steel cup, filled with mercury, inserted, and the weighted lever brought into play. The vertical shaft is now rotated, and, after the mercury has reached a certain temperature, the number of revolutions is ascertained, or the temperature of the mercury is measured after a given period of time has elapsed. In this way a number of lubricants were tested by the Dux-Bodenbach Railway. Each lubricant was subjected to four tests, each lasting ten minutes, with an interval of ten minutes between the tests. The apparatus was driven at a speed of seven hundred and seventy revolutions per minute, with a pressure of 33 kilograms (73 lbs.) on the cup containing the mercury. The following Table gives the results of these tests, the initial tem-

[1] Minutes of Proceedings, Inst. C.E., vol. lxx., p. 473.
[2] Organ für die Fortschritte des Eisenbahnwesens, vol. xix., 1882, p. 11.

perature of the lubricant in each case being 17° Reaumur (70° Fahrenheit).

Lubricants.	Reading of Thermometer in Degrees Fahrenheit.							
	After							Increase in Temperature.
	I. 10 min. Test.	I. 10 min. Interval.	II. 10 min. Test.	II. 10 min. Interval.	III. 10 min. Test.	III. 10 min. Interval.	IV. 10 min. Test.	
Tallow	114·0	89·6	121·0	93·6	127·4	102·8	132·4	93·2
"	115·25	90·5	122·5	94·5	128·5	102·2	132·8	94·5 [1]
"	117·50	91·0	123·5	96·0	131·0	106·8	133·9	95·5 [1]
Sewing-machine oil	119·75	89·6	127·0	99·5	131·0	106·25	133·3	95·0
Dutch linseed oil	118·4	91·4	123·0	97·25	128·5	100·4	134·4	96·0
Salad oil	125·6	92·75	131·0	106·25	133·25	110·75	137·4	96·7
Olive oil	120·9	99·5	129·2	106·25	134·3	113·5	138·8	100·6
Almond oil	127·0	96·0	132·0	107·4	135·5	111·8	143·6	105·2
Glycerine	130·0	100·6	138·90	106·25	141·0	110·75	147·90	109·6
Mineral oil	123·0	88·25	132·0	101·75	143·6	110·75	147·90	109·6 [2]
" "	125·6	91·0	136·4	99·0	154·4	116·6	162·0	123·7 [3]
Rapeseed oil	125·6	92·2	143·4	101·75	145·4	107·6	151·9	113·6 [4]
Butter	140·0	104·0	144·0	107·4	160·25	Evaporated		..
Petroleum	147·9	110·75	158·0	119·75	167·0	"		..

[1] Inferior quality. [2] Superior quality. [3] Inferior quality. [4] Superior quality.

The relatively cheapest lubricant is the one whose final increase in temperature multiplied by its cost gives the lowest product.

J. R. B.

Development of Coal-Production in Belgium and the neighbouring Countries.[1] By Emile Harzé.

The Author has compiled Tables of the coal-production of England, France, Germany, and Belgium, during the last fifty years, and from them has constructed diagrams with abscissæ corresponding to periods of five years, and ordinates giving the average yearly output of those periods.

As statistics are wanting in the case of England before the year 1854, the curve constructed from the output of the subsequent years has been produced hypothetically, giving the following figures for the previous five-yearly periods:—

	Mean Yearly Output. Tons.
1831–35	26,500,000
1836–40	30,500,000
1841–45	36,400,000
1846–50	45,500,000
1851–55	57,000,000

[1] From an original Paper in the library Inst. C.E.

Though the hypothetically produced curve cuts the point corresponding to the estimate of McCulloch for the year 1839, viz., 31,520,808 tons, it passes beyond, or outside, the point corresponding to his estimate (34,853,600 tons) for 1845, and that of Mr. Emerson Tennent for 1846, viz., 34,244,000 tons, while it falls slightly short of Mr. J. Dickenson's figure of 54,864,000 tons for 1851–52.

The curves corresponding to the outputs of the four countries above-named all begin to pass from a convex to a concave form (with reference to the datum line) during the last five-yearly period, thus showing a tendency towards diminished production; the convexity corresponds to the period during which steam locomotion was developed. When the curves are formed with ordinates corresponding to ten-yearly averages instead of five-yearly, that of Belgium alone shows a decided tendency to assume a concave form, the curve of Germany continues as convex as before, and those of both France and England show diminished convexity.

The Author deduces therefrom the law that, when active working is extended to all the productive parts of a country's coal basins, the curve will insensibly merge into a straight line, then become concave, and then, having attained its zenith, will approach the datum line, near which it will probably again assume a convex form.

J. W. P.

On the Basic Martin-Process at Alexandrowsky Steel-works.

By O. T. Tellander.

(Jernkontorets Annaler, 1882, p. 314; Stahl und Eisen, vol. ii., p. 599.)

This process, which, noticed as experimentally used in the Author's former description of the works,[1] has been adopted practically for more than a year, and about 14,000 tons of ingots have been produced by it. The furnaces used were the same as those previously described, the walls and hearth bottom being made of dolomite and tar concrete instead of silica. In the rebuilding of the furnaces the gas and air ports were built in Dinas bricks in the usual way, and upon these the bottom is made up of the dolomite mass to a thickness of 180 millimetres; the side walls, tapered from 460 millimetres below to 290 millimetres, are then filled in the same way, the mixture, which includes lumps of burnt dolomite of the size of a walnut, being compressed by red-hot rammers. The dolomite lining is isolated from the Dinas brickwork by a band, 150 millimetres broad, of a mixture of chromic-iron ore and gas tar. The roof arch, which is mainly supported by the iron-casing plates, is made of Dinas bricks. When the lining is completed, rail-ends are laid as closely as possible over the entire surface of the bed, and then iron plates

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[1] Minutes of Proceedings Inst. C.E., vol. lxviii., p. 421.

are laid against the walls. This, by preventing access of air, protects the tar from burning away until the dolomite mass has become fritted, and the swelling or scaling of the masses also prevented. The rail ends are left in the furnace as long as possible, being only removed when they show signs of welding together, the firing being continued until the lining is hard enough to resist the blow of a pick. This result is usually attained in one and a half days when fired with wood, and in two and a half days with gas.

The average composition of the different materials was as follows:—

	Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
Cleveland pig-iron	3·0—4·0	0·7 —2·2	1·2 —2·0	0·06—0·15	..
Finland "	3·0—4·0	0·3 —0·8	0·4 —1·1	.. 0·06	..
Cast scrap . . .	3·5—4·0	0·3 —1·0	0·4 —1·2	.. 0·05	..
Old rails . . .	..	..	0·25—0·65	0·04—0·20	..
Scrap iron . . .	..	..	0·2 —0·5		
" steel . . .	0·3—0·45	.. 0·02	0·03—0·1	0·01—0·05	0·4—0·8
Hematite pig-iron .	3·0—4·5	0·7 —1·2	0·03—0·05	0·06—0·18	..
Swedish spiegel .	3·5—5·0	..	0·03—0·05	..	10—20
Ferro-manganese .	5·5—6·75	0·08—0·15	0·08—0·15	..	50—80

The dolomite used contained 1; lime, 40; magnesia, 8–10; iron and alumina, 5; silica, 6–4; and water and carbonic acid 41 per cent.

After testing several trial mixtures with gradually moving proportions of phosphorus (from 0·5 to 0·69 per cent.), the following appears to have been adopted:—

Cleveland pig, 33; cast scrap, 10; Iron rails, 10; other malleable scrap, 30; steel scrap, 4; hematite pig, 4·5; spiegel, 6; ferro-manganese, 0·5 per cent.

In order to obtain a sufficiently basic slag, about 6 per cent. of limestone is added at the beginning, and made up into bricks of a mixture of slacked lime and roll scale towards the end. The latter is a substitute for the Swedish iron ore that was at first employed, but did not prove satisfactory owing to the large amount of quartz contained.

In charging, the Cleveland pig and limestone are laid upon the bed and covered with as much scrap as the furnace will hold. These being cold require about four hours to melt down. The remainder of the scrap is then added in lots of about 320 kilograms. The sill of the working door is only very slightly raised above the surface of the bath, in order that the slag, which at first runs very fluid, may in boiling flow out as much as possible of itself. When the whole of the materials are melted down, and the slags as completely drawn as possible, the bath is stirred and tests are taken. These, cast in the form of truncated cones, are hammered to disks of 5 millimetres thick, cooled in water and doubled under the hammer. The fracture must be fibrous throughout, without crystalline stripes. If this is not the case, about 60 kilograms of the lime and scale bricks are added, and, after fusion and removal of the resulting slag, the ball is again tested. The metal

is, as a rule, so soft, that it is necessary to double it twice, or even three times to get a fracture. If this is still crystalline in part, the same quantity of lime and scale is added, and so on, until the required temper is attained. The hematite pig iron is then added, after which another test is taken, when, if satisfactory, the spiegel is added, otherwise a short interval is allowed before making the latter addition.

The next test is forged to a disk at red heat, and cooled to dull redness in the air before quenching in water. This, when placed on an anvil with a depression 70 millimetres broad, must resist from six to seven blows of a 24-pound sledge before breaking. If it breaks before the sixth blow the metal is too hard, and the ball is allowed to stand for a time; but, if it requires more than seven, a further addition of spiegeleisen must be made. The final addition of ferro-manganese is then made, and, when well distributed, the charge is tapped. The metal has a decided tendency to rise in the moulds, and, to prevent this, water is poured in into the moulds immediately after casting.

The working time for the charge is nine hours and thirty-five minutes, both for large or small furnaces, the consumption of coal being sensibly the same in both. It is, therefore, contemplated to increase the capacity of all the furnaces to 10 tons. In addition, two hours and twenty minutes are required for repairs, heating up, and charging, so that only two heats can be got per working day.

The repairs requisite after each cast are effected with dry, moderately burnt dolomite for the bed, or with the tar mixture on the side walls, the hearth being carefully cleared of all particles of slag and adherent metal.

The tap-hole requires renewing every three or four days.

The mouths of the gas and air ports are repaired with a mixture of coke dust and coal tar. The tap-hole stopping is of a mixture of sand and clay, as in the ordinary process.

The hearth lasts out one hundred and fifty to two hundred charges; the arches, walls and ports require repairs after every thirty or forty charges.

The building of the furnace above the generators takes about seven days' work, with eight hands for shaft. The smaller size (6 ton) furnaces require six thousand Dinas, and one thousand five hundred Glenboig firebricks, 6,160 kilograms of ground dolomite, and 1,280 kilograms in small lumps, 1,040 kilograms of chromic-iron ore, and 1,120 kilograms of coal tar.

The results obtained from the continuous working of the process during the first five months of 1882, six furnaces, with a total of four hundred and twenty-eight working days, made eight hundred and thirty-four charges, producing 6,081 tons of ingots, with a total consumption of 7,040 tons of materials as follows:—

	Tons.		Tons.
Cleveland pig	1,970	Cast scrap	670
Rails	1,409	Other scrap	2,076
Hematite pig	303	Spiegel iron	577
Ferro-manganese	35		

The fluxing additions were limestone, 453 tons, and lime-scale bricks, 120 tons. The coal consumption was 5,503 tons. The yield in ingots was 86·4; in scrap, 2·6; and the loss, 11 per cent.

The ton of ingots per furnace required a hundred and one minutes' time, 905 kilograms of coal, and 1,157 of iron-producing material. The quality of the products is given as follows:—

	Mn.	C.	Si.	P.	S.	Tensile Strength.	Elevation.
						Kg. per mm.	Per cent.
Rail steel	0·4—0·8	0·3 —0·45	trace	0·03—0·07	0·01—0·03	50—60	15—25
Hard iron	0·3—0·5	0·2 —0·25	„	0·03—0·05	trace	40—50	20—25
Soft „	0·2—0·35	0·1 —0·15	„	0·02—0·03	„	35—40	25—30
Very soft iron	0·2—0·3	0·06—0·10	„	0·02—0·03	„	30—35	above 30

The dolomite is burnt in round kilns, with iron jackets 3·5 metres high and 1·75 metre diameter. The interior lining was originally made of the same material as that used in the melting furnaces, but it has been replaced by blocks of chromic iron ore from the Ural, which last for three or four months, as compared with fifteen days, which was the longest run got with a dolomite lining. The blocks are set with a mortar made of two parts, by measure, of powdered ore to one of lime. The kiln is filled with a bed of wood about 4 feet deep, covered by 2 feet of coke breeze from the generators, which are followed by the normal charge of 560 kilograms of dolomite to 260–300 of coke. When completely filled the wood is kindled, and the regular charging goes on, the kiln being drawn twice in twenty-four hours, usually giving 3,200 kilograms, equivalent to 51 per cent. of the weight of the raw stone. When cooled it is broken up by hand, and sorted into three qualities. No. 1, the hardest burnt, is compact and very dense. No. 3, on the other hand, is light and porous, and amounts to about 25 per cent. of the whole. No. 2 is intermediate in character. No. 3 is used exclusively for repairs. Nos. 1 and 2 are ground either in a Vapart crusher or under-edge runners, to be used in the tar mixture.

H. B.

On the Effect of Sulphur and Copper upon Steel. By A. Wasum.

(Stahl und Eisen, 1882, vol. ii., p. 192.)

Opinion is considerably divided as to the proportion of copper and sulphur that may be present in steel without injuring its working properties. Karsten, reproducing the opinion of the practical ironworkers of his time, states generally that copper makes iron red-short. Eggertz states that wrought iron with 0·5 per cent. of copper shows only traces of red-shortness.

Stengel draws the following conclusions from the results of a series of experiments:—

1. Sulphur to the extent of 0·116 per cent., and 0·192 per cent. of silicon, without copper, renders iron and steel red-short and useless.

2. Red-shortness becomes apparent with 0·015 of sulphur, and 0·44 of copper per cent.

3. The deteriorating effect of sulphur is much more energetic than that of copper, 0·1 per cent. of the former being probably more injurious to the strength of iron than 0·75 per cent. of the latter.

According to Eggertz, steel made from an iron containing only 0·5 per cent. of copper is worthless.

In America, greater importance is attached to the absence of sulphur and copper in steel than in Germany, 0·15 to 2 per cent. of copper being considered as too high.

In order to obtain more definite information as to the influence of these elements, experiments were made by the Author in 1875 at Bochum, by adding them both separately and together to the metal, in a converter containing 3-ton charges. Copper was added in the metallic form, and sulphur as sulphide of iron. The addition was always made before the charge was introduced, in order that the effect might be uniformly distributed through the mass. The ingots were rolled into rails, receiving the same reheating as those ordinarily made. A complete analysis was made in every case, in order to determine whether the red-shortness might not be due to other substances. The results obtained were as follows:—

No.	C.	Si.	P.	Mn.	S.	Cu.	Rolled.
			1. Copper alone.				
1	0·276	0·144	0·064	0·778	0·059	0·452	Very well.
2	0·233	0·091	0·050	0·709	0·060	0·862	Well.
			2. Sulphur alone.				
3	0·280	0·160	0·049	0·634	0·119	0·050	,,
4	0·393	0·141	0·065	0·695	0·158	0·040	,,
5	0·258	0·136	0·043	0·500	0·201	0·076	Badly.
6	0·307	0·075	0·039	0·488	0·214	0·057	,,
7	0·224	0·089	0·030	0·480	0·231	0·066	Very badly.
			3. Sulphur and copper together.				
8	0·311	0·051	0·061	0·514	0·107	0·849	Well.
9	0·281	0·169	0·059	0·594	0·170	0·429	Badly.
10	0·235	0·164	0·045	0·468	0·173	0·573	,,
11	0·262	0·131	0·052	0·655	0·189	0·406	,,

Charges Nos. 1 and 2 gave perfectly sound rails, with the exception of a few slight cracks at the forward ends. Nos. 3 and 4 showed a few unimportant cracks in the roughing rolls, which disappeared in finishing. Nos. 5 and 6 were strongly red-short, the rails being totally useless. No. 7 was very strongly red-short,

the ingots breaking to pieces in the first and second grooves of the rolls. No. 8 behaved like Nos. 3 and 4. Nos. 9, 10 and 11 produced rails that were defective without being totally useless.

From these experiments the Author concludes that the effect of copper in producing red-shortness has been over-estimated, as steel containing 0·862 per cent. was perfectly workable, and even in combination with sulphur it is not so very injurious if the latter is kept down below the limits at which it will produce red-shortness alone. As an extreme limit to be tolerated, the Author considers 0·15 to 0·16 per cent. of sulphur as likely to cause red-shortness, while 0·10 per cent. may be regarded as harmless. It may also be that, with softer and less manganiferous metal than No. 4, the injurious effect may be more marked, and in any case the less sulphur that is admitted the better.

H. B.

A Singular Case of Corrosion of Steel.

By Prof. Charles E. Munroe, U.S. N.A.

(Journal of the Franklin Institute, April 1883, p. 309.)

Through the kindness of Chief-Engineer Farmer, the Author's attention has recently been called to the appearance of two cold-chisels found in the U.S.S. "Triana" in 1874, and which have since been preserved in the Department of Steam-Engineering at the Naval Academy. These chisels were taken from the channel-way leading from the jet-condenser, and they were located between the foot-valve and the air-pump. Both chisels were of steel throughout, as was proved by tempering the head. For use, of course, only the points had been tempered. During the time of exposure to the action of the salt water in the channel-way, the chisels were deeply corroded, but the corrosion was confined entirely to the soft metal, the tempered points not being attacked in the least. The corrosion was deepest at the line of contact between the tempered points and the untempered metal of the haft. The line of immersion, on tempering, was as distinctly marked as if drawn with a shading-pen. Since meeting with these chisels, the Author has heard of a similar case of corrosion, although the object has been lost. It was a hammer which had been taken from the boiler of a merchant steamer, the tempered faces of the hammer were intact, while the soft metal was corroded.

The Author does not attempt to decide whether the change which takes place in the tempering of steel is a chemical or a physical one, but it is evident that this change produces a body which is not so readily acted upon by salt water as untempered steel is. It is also probable that, when the untempered and tempered steels are brought in contact in the presence of salt water, they constitute an electro-chemical couple, and that this hastens the

destruction of the untempered metal. The Author suggests that this observation may have a practical bearing upon the construction of steel ships.

*

On the Manufacture of Magnesia Bricks.

(Bulletin de la Société d'Encouragement, 3rd series, vol. x., 1883, p. 43.)

The following methods are described by Mr. Massenez, of Hörde, as in use for the purpose of producing caustic magnesia bricks for the Basic steel process. The advantage of this material over calcined dolomite is due to its indifference to water, so that it can be rendered plastic and moulded wet without becoming hydrated, as is the case when lime is present. There is an objection to the use of limings made from natural magnesite, partly on account of the expense, but more particularly on account of the notable proportion of silica present, which is likely to have a fluxing effect at the high temperatures in use in the steel furnaces.

The first method, that of Mr. Prosper Clonan, is applied in the treatment of the waste water of the potash works at Stassfurth, which contain 372·7 grams of chloride of magnesium per litre. These, when heated with burnt dolomite, are decomposed according to the following reading:—

$$Mg\,Cl_2 + CaO\,MgO = Ca\,Cl_2 + 2MgO.$$

The process is effected by mixing ground dolomite with water and the magnesian chloride liquor, and heating the mixture in vats with agitators, until the carbonic acid is completely expelled, which is very quickly done; the precipitated hydrated magnesia is then washed, pressed, and dried. As it is perfectly plastic, it can be readily moulded.

Eight and three quarter tons of Stassfurth chloride liquors and 1¼ ton of dolomite are required to produce 1 ton of magnesia; the cost of manipulation, including decomposition, washing, and moulding, does not exceed 4*s.* per ton of bricks.

Another method of equal simplicity, but which has the further advantage of being available wherever dolomite can be got, has been recently described by Prof. B. Scheibler, of Berlin, who removes the lime by digestion in weak solution of sugar. The method is as follows: dolomite, previously diffused through water, is mixed with syrup containing 10 to 15 per cent. of volume by sugar, and heat is applied until the carbonic acid is expelled. In a few minutes soluble saccharate of lime is formed, while the magnesia separates as hydrate, and may be collected by decantation. By heating the solution the saccharate of lime is decomposed and lime precipitated, so that the sugar solution is renewed, and can be used for the further decomposition of dolomite with success.

Both of the above methods have been tried with success at Hörde, and the cost appears to be about equal in either case; the composition of the magnesia obtained being,

By Scheibler's process:—

	Per cent.
Silica, oxide of iron, and alumina	1·47
Lime	2·18
Magnesia	95·99
	99·64

By Clonan's process:—

	Per cent.
Silica, oxide of iron, and alumina	1·05
Lime	1·94
Magnesia	96·60
	99·59

Bricks and other furnace-lining pieces may be made from the hydrated magnesia without any difficulty, the moulded material firing without cracking or irregular shrinking. Converter-bottoms, so obtained, are remarkably homogeneous, hard, and dense, and, while costing no more than those made of dolomite, are sensibly more durable.

H. B.

On the character of Induced Currents resulting from reciprocal movement of Two Magnetic Bodies parallel to their axes.

By T. du Moncel.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, pp. 214–216.)

If there be moved longitudinally before a bar electro-magnet, the helix of which is connected to a galvanometer, one of the poles of a permanent magnet, three induced currents are successively developed. One results from the approach of the inductor-pole; another, of opposite direction, from the movement of the inductor along the electro-magnet; and the third in the same direction as the first, due to demagnetisation of the opposite end of the electro-magnet. If, however, the inductor-pole be made by a sweeping movement to comprise the three phases, the galvanometer indicates a single current only, corresponding to the movement of the inductor-pole along the magnet, and this is the stronger because it results from a reaction effected nearer the magnetic core of the electro-magnet. This current has been named by the Author as that of polar interversion.

If the iron core of the electro-magnet be polarised by putting it in contact with a pole of an electro- or other powerful magnet, and the preceding experiment be repeated, this polarisation exercises no influence on the direction of the induced currents, but their

intensity is altered, being greater when the poles opposed in the movement are of opposite name. It is only the nature of the inductor-pole or of the direction of winding of the induced electro-magnet that has action upon the direction of the currents. The Author concludes that the polarisation of an iron core immobilises a certain quantity of magnetism, that remains consequently indifferent to the dynamic excitations of external magnetic reactions, and that is of influence only when, perhaps reacting on the inductor, the energy of which it super-excites, it can polarise in its turn, so that action and reaction are effected in a concordant direction. Thus a very feeble magnet may determine actions that are very different to those exercised by the soft iron. As a consequence to be drawn from this kind of effect is that the induced currents due to approach of the inductor are of the same direction as the current which has magnetised it, when the opposed poles, at approximation, are of the same name, the inverse to ordinary cases of magneto-electric induction. This may perhaps explain why in the Griscom motor benefit is obtained from the induced current developed.

The Author has ascertained that the preceding effects are the same with a closed and with an open electro-magnetic system, as regards direction but not intensity. The closed system was obtained by polarising both ends of the electro-magnet at once; the open, by polarising a single pole. Thus the currents due to approach of the inductor, which, with poles opposed of contrary name and with the open magnetic system, are more energetic than when these poles are of the same name, become, on the other hand, less energetic with the closed magnetic system. The currents due to approximation are nearly of double the intensity in the open system as compared with those from the closed system. When, instead of a complete magnetic system, the iron core of the electro-magnet is omitted, the sweeping movement gives nearly a *nil* current, which shows that the action of the magnet on the wire is infinitely less than the action of the magnet on the magnetic system occupying the centre of the helix.

P. H.

On the best Arrangement of Earth-Plates for Electrical Conductors. By Dr. R. Ulbricht.

(Elektrotechnische Zeitschrift, 1883, p. 18.)

The resistance of a hemispherical electrode (radius R) buried in the earth, when the opposed electrode is at an infinite distance is given by the expression $(2 k \mathrm{R} \pi)^{-1}$, where $\mathrm{K} \times 10^{-6}$ is the specific resistance of the medium enclosing it, R being determined in metres. The Author has, by a method of approximate integration, developed similar expressions for electrodes of various forms; the results of which are finally exhibited in the following practical

form, which shows the dimensions, for the form specified, for electrodes offering an equal resistance, the values being in metres:—

A square plate,	horizontal,	length of side equal 1		
„ cylinder,	vertical,	„ 1·4	diameter	0·13
„ „	„	„ 1·8	„	0·06
„ bar,	„	„ 2·6	„	0·013
„ „	horizontal,	„ 5·2	„	0·013
An annular disk,	„	outside diameter 1·32		inside 1·08
A wire netting,	„	a square		length of side 1·01
„ „	„	length 3		breadth 0·16
„ „ formed as an annular ring	„	outside diameter 1·26		inside 0·94

The wire netting specified is constructed of 2·5-millimetre (0·1 inch) wire, the meshes being hexagonal, and 5 centimetres (2 inches) centre to centre.

As regards material, copper, though expensive, presents advantages in the direction of durability and ease of manipulation; the form will depend on the nature of the ground and the facility with which it can be excavated; wire-netting gives an efficient conductor at a low cost and at very little more expense in the way of excavation. The electrode should be sunk with its centre at a distance below the surface equal at least to its greatest dimension; but the best rule is to place its upper surface at such a depth as to be in ground essentially moist; and to obtain evidence on this point excavation to the required depth is desirable. The necessity of such a course is particularly enhanced by the fact that nine-tenths of the resistance is offered by the earth contained within a circumference of ten radii of the electrode. A stream of water, ditch or spring, afford most suitable positions, at the same time dispensing with all earth-work. A comparison by actual experiment was made between two electrodes formed of a square solid plate, and an annular ring of wire-netting respectively, the results being closely in accordance with the theoretical values deduced from their dimensions.

F. J.

On a New Means of Insulating Electric Conductors.

By H. Geoffroy.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcv., 1882, p. 331.)

The object proposed to be gained is to prevent all chances of fire, even if the wires come in contact with combustible matter. The conducting wires are surrounded with asbetos-fibre, and placed in a lead tube. One experiment on a short piece of such a conductor, in which the inner wire was volatilized by the strength of the current, proved that the lead tube showed no sign of melting.

E. F. B.

On the Formation of Secondary Batteries with Lead Plates.

By G. PLANTÉ.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcv., 1882, p. 418.)

This process, as is known, consists in oxidising one of the electrodes, and reducing the other to a state of metallic division, so as to permit the most complete chemical action during the charge and discharge, and hence to accumulate a larger quantity of the chemical work of the primary current. After having experimented for years on the various combinations, and most of the soluble and insoluble compounds of lead, the Author has finally arrived at the conclusion that the best arrangement is to endeavour to transform the metal of the electrodes, nearly through its thickness into galvanic peroxide of lead on the one hand, and reduced lead on the other. This result has been arrived at by a series of changes of the sign of the primary current, with intervals of rest between the changes.

With a secondary battery thus partially formed, of which the lead weighed 1½ kilogram (3·3 lbs.), the discharge-current, which furnished at first a deposit of 7 grams (108 grains) about of copper, after a new change gave a deposit of 11 grams (170 grains, and after a third 18 grams (279 grains), or 12 grams per kilogram (84 grains per lb.) of the secondary couple, the equivalent to 36,000 coulombs. And this is not the attainable limit, as, assuming that half only of the thickness of the lead is transformed, the other half being retained as the body of the electrode, by this means it is hoped to obtain a deposit of 74 grams of copper per kilogram weight of the secondary couple, or 7½ per cent.

This system of alternate changes of the current does not only increase the layer of peroxide of lead formed at the expense of the metal of one of the electrodes, but changes to a corresponding depth the other electrode into galvanic lead, so that at the time of discharge, whilst the hydrogen produced from the decomposition of the water in the interior of the couple, reduces the peroxide of lead formed by the primary current, the oxygen can at the same time oxidise an equivalent quantity of lead. The value of the intervals of repose may be explained by considering that after a time the lead plates conduct less efficiently at their surface, whence it results, that when again submitted to the action of the primary current, this current naturally, in traversing the liquid, follows the line of least resistance, it does not pass out by the oxidised surface, but by the subjacent metallic surface, to which the liquid has already penetrated. A new layer of metal is thus oxidised, and that already oxidised is more and more affected. Thus a sort of galvanic cementation takes place, at the end of which the two plates are quite altered in structure, one being a crystalline lead, and the other crystalline peroxide. In these conditions the battery will retain its charge for four months. This method is rather

lengthy; it was found that increasing the temperature of the liquid during the action of the current accelerates the formation of the couple. But the employment of heat occasioning some practical difficulties, these have been surmounted by a sort of scouring with dilute nitric acid, for forty-eight hours. The couples are then emptied, washed, and filled with sulphuric acid, diluted with ten parts of water, and submitted to the action of the primary current. Some of the lead is doubtless dissolved by the dilute nitric acid, but the thickness of plates is not much reduced, whilst its porosity is increased and galvanic action thus intensified. At the end of a week, batteries thus prepared produce results which were only previously attainable after some months.

E. F. B.

On a Modification of the Bichromate Battery. By G. Trouvé.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 787.)

This is a description of an improved method of preparing the exciting-liquid of a bichromate battery, that remedies the inconstant action of batteries of this class, and prevents the formation of chrome-alum on the carbon-plates. The Author finds no advantage in placing in the liquid reservoirs of acid and bichromate, as sometimes adopted; but he finds the double defect of inconstancy and the deposit of chrome-alum avoided by the use of supersaturated bichromate solutions. One hundred and fifty grams of the bichromate in powder are dissolved in 1 litre of water, and the solution having been agitated, 450 grams of sulphuric acid are added drop by drop. The Author states that by this method he has succeeded in dissolving as much as 250 grams of bichromate in the same quantity of water; and that the bichromate will not dissolve in a solution already acidulated.

The elements of the battery are formed of a plate of zinc and two carbons electrotyped with copper at the upper part. The coppering consolidates the carbon and diminishes the resistance. Twelve cells [size not given] are stated to feed for five hours ten incandescence-lamps, each of 10-candle power; and four cells developed on a small Gramme dynamo 14 kilograms a second during two hours, without weakening notably in intensity.

P. H.

History of Modern Dynamo-Electric Machines.

By A. von Waltenhofen.

(Wiedemann's Annalen, vol. xviii., 1883, p. 253.)

The Author considers the modern dynamo-machine to be the outcome of the Paccinotti continuous induction-ring armature, and Werner Siemens' principle of mutual accumulation, but the ques-

tion arises as to whom the merit of combination is due, and this appears to have occurred to Professor Pfaundler, of Innspruck, in 1867.

While Jacobi (1840) furnished the basis of a theory of electro-magnetic motors, Grove (1844), Joule and Scoresby (1847), and Petrie (1851), must be accredited as those who have given exact information concerning the effective work of these motors. Petrie can alone be regarded as having given reliable data, and is also the only one who expressly states that he has taken into account that the theoretical work effected in proportion to the unit of weight of zinc depends upon the nature of the circuit in which the consumption of zinc takes place. The Author considers the method of arriving at the weight of zinc consumed, by weighing the plates before and after the experiment, to be clumsy and inaccurate, and in his own researches has taken the measurement of the current by the tangent-galvanometer, and reckoned, from the product of the current and the known electro-motive force of the battery, the effective work in kilogrammetres per second, and, by comparison of the effective work so determined with the work measured with the brake dynamometer, deduced the efficiency of the machine.

Let J be the battery current in the motor when stationary, and $J - i$ the current during working of the motor, i being the counter-current induced, λ the total resistance of the circuit; then

$$J \lambda (J - i) = i \lambda (J - i) + (J - i)^2 \lambda.$$

The first term represents the current work given off from the battery when the motor is driven, or the total work D; the second, the mechanical work performed in the machine, comprised of useful work and friction; and the third, the heat-work in the circuit. The efficiency is as N : D. To find D the Author employs the galvanometer to measure $J - i$, the other factor, or the electro-motive force $J\lambda$, being given.

P. H.

On the Theory of Electro-magnetic Machines. By M. Joubert.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 641.)

This note refers to the loss of work in a machine, besides that consequent from Joule's law. The Author believes the following cause to be the most important. All continuous-current machines, consisting of a certain number of elements, as those of the coils of the Gramme ring, in the case, for example, where the machine acts as a receiver, pass from a position where the potential energy has a maximum value W_0 to another diametrically opposite, of minimum value W_1. The difference $W_0 - W_1$ represents the electro-magnetic work furnished by the coil in passing from the first position to the second. So that the movement may be continuous, it is necessary at this instant to reverse the direction of

the current in the coil, that is, to destroy at a pure loss the electric energy it possesses, and to restitute integrally the primary energy W_0. The operation is repeated twice in each revolution for each coil. Omitting the work due to resistance, the efficiency is then $\frac{W_0 - W_1}{W_0}$. It is easy to evaluate the inferior limit of the electric energy lost at each semi-revolution, and partly manifested as sparks. Let I_1 be the quantity of current at the instant of change in the coil, and l the coefficient of self-induction of the coil, the loss will have for its value $\frac{l\,L^2}{2}$. If the ring consists of p coils and makes n revolutions in a second, the loss in each unit of time is then at a minimum $n\,p\,l\,I_1^2$ or $n\,L\,I^2$, L being the coefficient of self-induction of the entire ring.

Analogous considerations apply to the generating-machine. All the coefficients intervening in the equations may be determined directly.

P. H.

Electric Transmission of Power.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 332.)

This is a translation of the official Report of the Commission of the Electrical Exhibition of Munich on the experiments made in September 1882, with two identical Gramme dynamoes, by Mr. Marcel Deprez, on 35½ miles of telegraph wire of 0·176 inch diameter. The power was furnished at Miesbach from a steam-engine, and the motor maintained in the Crystal Palace at Munich, a cascade of water of about 8 feet in height.

The results obtained, under very unfavourable circumstances, are given by the Professors Dorn, Kittler, Pfeiffer, and Schröder, as follows:—

	Ohms.
Resistance of the line	950·2
" " machine at Miesbach . . .	453·1
" " " Munich	453·4

At Munich the potential difference was 850 volts, and the number of revolutions 752.

At Miesbach the number of revolutions was 1,611, and the quantity of current 0·519 ampères = I.

Difference of potential at Miesbach $E_1 = E_2 + 950 \times I = 1343$ volts.

Electric work: external, $E_1 I = 697$, or in French HP. $= \frac{E_1 I}{736} = 0·947$.

Total electric work: $E_1 I + I^2 \times 453·1 = 819$; in HP. $= 1·13$.

Heat-work in whole circuit: $I^2 \times 1856·7 = 500$; in HP. $= 0·680$.

Disposable work for transmission of power: $E_2 I - I^2 \times 453·4 =$

319; in HP. = 0·433; and in percentage of total electric work 38·9. The experiments are considered to be under such unfavourable circumstances as to be inconclusive.

P. H.

Results of Experiments by Mr. Marcel Deprez, at the Workshops of the Northern Railway of France, on the Electrical Transport of Power to great Distances.

By H. Tresca.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 457.)

These experiments [date 11th of February 1883] were made over a total length of 17,000 metres of telegraph-wire of 4 millimetres diameter, having a resistance of 160 ohms. The generator was a machine of special construction as regards the form of its armatures, which were of double coil of wire 1 millimetre diameter; the receiver was a large modified Gramme dynamo. The resistances of the two machines were respectively 56 and 83 ohms. The following may be accepted as typical of the reduced results:—

	HP.
Electrical work of the generator	4·64
Intermediary loss	1·34
Electrical work in the receiver	3·30
Intermediary loss	0·51
Work really transmitted	2·79
Efficiency of the circuit	0·711
Efficiency of the receiver	0·845

P. H.

New Equations relating to the Transmission of Power.

By Marcel Deprez.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcvi., 1883, p. 777.)

The Author has previously shown that, by the intervention of a new element, termed the "price of static effort," equations relating to the transmission of power by electricity may be rendered exempt from electrical symbols, and made to contain quantities only of a mechanical order. One of the advantages arising from this is, that the relations can be grasped by those mechanicians who are unacquainted with electrical dimensions. But the Author deems it necessary to remark that the hypothesis of an electrically and mechanically perfect machine must obtain, but considers as certain that in machines of large dimensions the useful work is related to the theoretical work by the coefficient 0·9, so that, if

the electrical return is, for example, 0·67, the industrial mechanical return, or efficiency, attains $0 \cdot 67 \times 0 \cdot 9 \times 0 \cdot 9 = 0 \cdot 54$.

The following equations are applicable only in the particular case where the current is sufficient to saturate the magnetic fields of the two machines. Let

- F_0 be the tangential effort (in kilograms) applied to the generator at a distance from the axis equal to $\frac{1}{2\pi}$ (corresponding to a circumference of a metre);
- V_0 the velocity in metres per second of the point of application of this effort;
- f_0 a coefficient depending on the construction of the machine;
- F_1, V_1, f_1, corresponding quantities for the receiver;
- I the quantity of the current, and R the total resistance of the line and machines.

The magnetic fields of the two machines being saturated, the tangential effort is, in each, proportional to the quantity of the current, or $F_1 = f_1 I$, $F_0 = f_0 I$; from the first of these equations $I = \frac{F_1}{f_1}$, and the second becomes $F_0 = \frac{f_0}{f_1} F_1$.

The work lost as heat in the whole circuit, being equal to $\frac{R I^2}{g}$ or $\frac{R}{g}\left(\frac{F_1}{f_1}\right)^2$, must be subtracted from the work absorbed by the generator, and there remains for the useful work returned by the receiver,

$$F_1 V_0 \frac{f_0}{f_1} - \frac{R}{g}\left(\frac{F_1}{f_1}\right)^2$$

where the first term is the work absorbed in the unit of time by the generator, or $F_0 V_0$. And the economic return has for expression,

$$\frac{F_1 V_0 \frac{f_0}{f_1} - \frac{R}{g}\left(\frac{F_1}{f_1}\right)^2}{F_1 V_0 \frac{f_0}{f_1}} = 1 - \frac{R F_1}{g V_0 f_0 f_1}.$$

These equations give the work expended by the generator, the work returned by the receiver, and the economic efficiency, in function of the velocity V_0 of the generator and of the load on the brake F_1 at the receiver. They contain no other electric element than the total resistance.

P. H.

The Transmission of Energy by Means of Dynamo-electric Machines. By G. E. CABANELLAS.

(Résumé de la Société des Ingénieurs Civils, Paris, 1883, p. 109.)

The Author points out the inadequacy of the usual equations of the first approximation to meet observed facts, and insists very strongly upon the importance of the effect of the velocity of rotation in varying the effective magnetism of the field independently of the current, which may or may not remain uniform. That is to say, he holds that the effective magnetism is a function of the velocity as well as of the current. Thus he entirely disagrees with some of the deductions at which Mr. Marcel Deprez has arrived, *e.g.* that the value of the turning couple is independent of the velocity when the density of the current round the electro-magnets is constant, and with the value of the efficiency which the latter claims to have reached in his experiment at Munich. Another point which the Author thinks is generally insufficiently or not at all considered, but on which he himself has for some years insisted, is the change in the internal resistance of a machine brought about by the velocity. This change is an increase for an increasing velocity, and affects those parts of the circuit which undergo alternation of direction of current, *e.g.* the armature-coils in ordinary machines with collectors. The effect is proportional to the velocity, and ultimately counteracts the advantages gained in increased electromotive force by a finely-wound armature.

The Author examines the Munich experiment from this point of view with the result of arriving at 17 : 100 as the value of efficiency then attained.

T. H. B.

[NOTE.—The Author's views have been the subject of much adverse criticism, dating from their first emission at the International Congress of Electricians in 1881. See "Congrès international des Électriciens, Paris 1881. Comptes rendus des Travaux. Paris. G. Masson, 1882," p. 347 *et seq.*—T. H. B.]

On Telephoning over Long Distances or through Cables. By N. D. C. HODGES.

(Proceedings of the American Academy of Arts and Sciences, 1881–2, p. 268.)

Within any conductor connected with the earth, the only electrical forces against which work has to be done during the movement of electrified bodies are those due to the mutual action between the charges in these bodies, and not to the charges which may exist outside the conducting-surface. So that, in causing a movement of electricity from A to B, the work is the same when A and B are inside a conducting-surface as when they are outside;

and to cause a current along any course from A to B the same amount of energy will be required as if the system A B were in open space. Hence in the case of a double-wire cable of no great length compared with its section, so that the resistance of the wire should not be sufficient to cause it to act like a succession of short pieces, the source of the electromotive force being contained in a conducting surface continuous with the outside of the cable, a current could be produced as easily as in an air-line.

In the case of a cable there is a condenser to deal with, the circuit wire being the inner, and the water outside the outer surface. In order to cause a current to flow through a conductor situated in this way, a quantity of electricity must be supplied sufficient to raise the potential along the conductor to such a degree that the required current may flow.

To raise the charge of a conductor, the work to be done is expressed by $\frac{1}{2}\,\epsilon\,V$, where ϵ is the final charge of the conductor and V its potential; or, in terms of the capacity and potential, $\frac{1}{2}\,q\,V^2$. For a single wire, surrounded by a homogeneous non-conductor to an indefinite distance, the electric capacity is $\frac{1}{2}\,\frac{l}{\log \frac{l}{a}}$, where l is the length of the wire and a its radius. For a wire surrounded by a homogeneous dielectric to a limited distance, the capacity is $\frac{1}{2}\,\frac{K\,l}{\log \frac{a_1}{a_2}}$, where K is the specific inductive capacity of the dielectric, and a_1 and a_2 the inner and outer radii of the dielectric.

As the energy required to charge a condenser is

$$W = \tfrac{1}{2}\,q\,V^2,$$

and as no work is done in moving the one conducting-surface within the other, the same expression for the work done in charging a cable will hold when the wire is not concentric with the outside as when it is, as was supposed in the above. Hence the work required to charge a unit length of cable, even when the wires are not in the centre, will be equal to

$$W = \tfrac{1}{2}\,q\,V^2 = \tfrac{1}{2}\,\frac{K}{\log \frac{a_1}{a_2}}\,V^2.$$

On account of this static capacity of a cable, there is a retardation in the transmission of signals from the greater amount of energy which must be supplied from the electrical source before the potential along the wire will be raised sufficiently to cause the required current; just as, in the case of heat, the specific heat of a bar determines how much heat must be given to one end of the bar before heat will flow along the bar at any given rate.

With a single-wire cable let V be the potential at any point of the wire. Let Q be the total quantity of electricity which has passed through a section of the cable at that point since the beginning of the current. Then the quantity which at the time t exists between sections x and $x + \delta x$ is

$$Q - \left(Q + \frac{dQ}{dx} d x\right), \text{ or } -\frac{dQ}{dx} \delta x,$$

and this is equal to $q \, V \, \delta x$. Hence

$$q V = \frac{dQ}{dx}.$$

With a double-wire cable when used to form a metallic circuit, the two wires being connected to the two poles of the battery or transmitter, or whatever the electric source may be, the quantity of electricity flowing across any section of the cable on one of the wires will be equal and of opposite sign to that on the other. Hence the total quantity flowing across any section of the cable will be zero, and $d\,Q$ will be zero. So that the potential to which the condenser, consisting of the two wires and the outside surface of the cable, will be raised will be zero, and the energy required from the battery no greater, on account of the nearness of the water, the second conducting-surface of the condenser.

There is one thing to be considered, that the wires, being covered with some insulating material which cannot be made perfectly homogeneous, they, with the broken nature of the dielectric about them, will each form a condenser to some extent. It would therefore appear that, as far as the retardation is due to the static capacity of a cable, it can be greatly reduced by using a double-wire cable with homogeneous insulating-material.

In support of this view there are the experiments made by Wheatstone, and described in the Proceedings of the Royal Society for 1854–55. Wheatstone made experiments on a cable of six wires intended for use in the Mediterranean. The length of the cable was 110 miles. On connecting one of the wires with one pole of his battery, the other pole being to ground, he found that quite a time was required before the flow into the cable fell to the rate due to leakage. On connecting one pole of the battery with one wire and the other with another, the charge which the cable-wires would take was reached instantly.

On long land-lines the static capacity of the line is due, outside of the capacity of the wire, to the neighbourhood of the earth. This has been found to affect the articulation in telephoning on the line from Boston to Baltimore, 500 miles in length. By the use of a complete metallic circuit the articulation was greatly improved.

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Experiments on the Telephone. By A. D'ARSONVAL.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcv., 1882, p. 290.)

These experiments were made with the object of determining in what manner the wire of a telephone should be placed as regards the magnet, so as to produce the maximum of effect upon the vibrating diaphragm. The results prove that the construction of the telephone should resemble that of the best dynamo-machines; its force is much increased by causing both poles of the magnet to act on the diaphragm, the wire being placed between the poles flattened out and brought close together. That the whole of the wire may be under the influence of the magnetic field, an annular form is given to it, such as already used in some electro-magnets. One of the poles, terminating in a cylindrical curve, carries the bobbin, the other is in the form of a ring surrounding the former. Thus all the lines of force are perpendicular to the direction of the wire, and are affected to a maximum degree. The result can be obtained by a variety of forms, of which the Author has chosen that of making the magnet a single convolution of a helix, by which means the lines of force can be concentrated in the annular space; one end of the spiral carries the cylindrical core, the other terminates in a ring. The two poles must be the same plane and close to the diaphragm, the bobbin is placed in the free portion. The instrument weighs about ten ounces: a drawing of it accompanies the original article.

E. F. B.

The Telephone and Induction. By Dr. VICTOR WIETLISBACH.

(Centralblatt für Elektrotechnik, formerly Zeitschrift für Angewändte Elektricitäts-lehre, 1883, p. 13.)

The experiments of Herz and Rysselberg prove that telephonic communication is possible over lines of considerable length, though the practical solution is not yet attained, due probably to the unsuitability of the instruments hitherto used. It is found, for instance, that though the thin steel diaphragm of the American type of telephone speaks with clearer articulation on short lines, on longer ones the thicker plate of the Siemens' form gives far better results. The Author here theoretically determines the maximum distance over which such communication is possible, considering the limiting effect of the nature of the conductor in the first place, and, secondly, the interference of neighbouring lines. On the first point the rate of transmission of electric waves is a function of the resistance and electrostatic capacity of the circuit, the increase in the product of these two quantities corresponding with diminution in amplitude and velocity of the wave. This retardation is also a function of the rate of vibration of the sound,

so that if the assumption is made that each sound must have a duration of at least $\frac{1}{10}$ second, and a retardation of not more than $\frac{1}{100}$ second between the highest and lowest tones be allowed, the limiting-distance for an underground-cable similar to the type adopted by the German Government would be 1,300 kilometres (800 statute miles), about the distance between Berlin and Paris or Vienna. As the capacity on overhead lines is, however, considerably less, the limiting-distance in their case would be much greater. On the second point distinction must be made between the disturbance resulting from electrostatic and electrodynamic induction; the first can be prevented by enclosing the insulated conductor in a metallic sheath, as has already been done. The second is, however, not easily prevented. It can theoretically be overcome in certain cases by increasing the resistance of the receiving-instrument to a value considerably exceeding that of the lines, but as this also reduces the sensitiveness of the sending-instrument, and the dimensions would so rapidly increase with the length of the line, this method is not practicable. On short lines, Professor Hughes' induction-balance might be applied, but this again exceeds the limits of practicability for more than two or three parallel lines. The only real way out of the difficulty is the use of a metallic return-circuit entwined with the original conductor, so that the induced currents are balanced on the two parts of the circuit. The especial difficulty in any other solution of this problem is that the induced currents are more powerful than those excited by the microphonic sender; hence the numerous proposals for increasing the action of the latter.

F. J.

On the Application of the Mechanical Theory of Heat to the Phenomenon of Magnetisation. By ANTON WASSMUTH.

(Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, vol. lxxxvi., 1882, p. 539.)

The Author, in pursuing his investigations [1] on the influence of temperature on magnetisation, has concluded from theoretical considerations that in general the magnetic moment of soft iron, subjected to a magnetic force, decreases with an increase of pressure; but if the magnetisation of the iron approaches its maximum value, an increase of pressure produces an increase of magnetic moment. The effect of temperature is the reverse of this —a rise in temperature corresponding to an increase in magnetic moment for weak magnetisations.

To confirm these conclusions experimentally, the Author enclosed a bar of iron, 9·4 grams in weight and 243 millimetres long, in a strong glass tube drawn out at one end into a capillary

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[1] Minutes of Proceedings Inst. C.E., vol. lxxi., p. 517.

tube filled with mercury, but otherwise closed. By warming the tube the pressure to which the iron was subjected could be increased, while it could be readily measured by means of the mercury-gauge. The bar was magnetised by a coil wound about it, and the magnetisation measured by a mirror galvanometer, the effect of the coil on the galvanometer being compensated by a second coil properly situated. The experiments were made at temperatures of 20° and 47° C. (corresponding to 10 atmospheres pressure), and again at 20° for different intensities of current in the magnetising coil. After correcting for the effect of temperature, the results showed a diminution in magnetic moment for the high pressure, until the curve of magnetisation began to break away from the straight line when an increase in magnetic moment became apparent. Further experiments on two other bars gave similar results, the increase of the maximum moment being about 0·2 per cent. for an increase of pressure of one atmosphere.

These results are of considerable interest in connection with the observed effect of earthquakes and volcanic eruptions on the declination-needle, in which variations of pressure probably play an important part.

In the second part of the Paper the Author discusses the application of the laws of thermo-dynamics to several points in connection with the theory of magnetism. Let the quantity of heat dQ, measured in mechanical units, be communicated to a unit of mass of iron, and let the consequent increase in internal energy be $d\Pi$. Then, if p be the hydrostatic pressure to which the iron is subjected, dv the increase in volume, $d\mu$ the change in magnetic moment, T the absolute temperature, and κ the magnetic force, it follows from the first law of thermo-dynamics that:—

$$dQ = d\Pi + p\,dv - \kappa\,d\mu \quad \ldots \ldots \quad (1)$$

and from the second law—

$$\frac{dQ}{T} = dS \quad \ldots \ldots \quad (2)$$

But since Π, v, μ and S are dependent only on the initial and final conditions, $d\Pi$, dv, $d\mu$, and dS are perfect differentials, hence, taking p and T as independent variables,

$$\frac{dQ}{dp} = \frac{d\Pi}{dp} + p\frac{dv}{dp} - \kappa\frac{d\mu}{dp} \quad \ldots \ldots \quad (3)$$

and

$$\frac{dQ}{dT} = \frac{d\Pi}{dT} + p\frac{dv}{dT} - \kappa\frac{d\mu}{dT} \quad \ldots \ldots \quad (4)$$

whence by differentiation and subtraction,

$$\frac{d}{dT}\left(\frac{dQ}{dp}\right) - \frac{d}{dp}\left(\frac{dQ}{dT}\right) = -\frac{dv}{dT} - \frac{d\kappa}{dT}\cdot\frac{d\mu}{dp} - \frac{d\kappa}{dp}\cdot\frac{d\mu}{dT} = \frac{1}{T}\frac{dQ}{dp} \quad (5)$$

Assume further as an experimental result that $\left(\frac{d\,\kappa}{d\,p}\right)_T$ is equal to $-\frac{L}{\kappa}$, where L is a positive constant. This is to some extent justified by the experiments of Righi, who found the extension of a bar on magnetisation approximately proportional to κ^2, and consequently the diminution in pressure dp proportional to $2\kappa d\kappa$, the temperature remaining constant. Similarly, reasoning from the experiments of Joule and Herwig, who have found that the rise in temperature of the iron is proportional to κ^2, it follows that $\left(\frac{d\,\kappa}{d\,T}\right)_p = \frac{K}{\kappa}$, where K is a positive constant. Hence, substituting in equation (5)

$$-\frac{d\,v}{d\,T} - \frac{1}{\kappa}\left(K\,\frac{d\,\mu}{d\,p} + L\,\frac{d\,\mu}{d\,T}\right) = \frac{1}{T}\,\frac{d\,Q}{d\,p}.$$

If the influence of magnetisation on the quantity of heat generated by compression is appreciable, it must be more apparent as the magnetisation increases, but it is evident the second term on the left of the equation approaches zero, as κ increases, since it is known from experiment that $\frac{d\,\mu}{d\,p}$ and $\frac{d\,\mu}{d\,T}$ are always very small, hence the sum $K\,\frac{d\,\mu}{d\,p} + L\,\frac{d\,\mu}{d\,T}$ is either zero or very small. The heat, therefore, generated by compression of iron is appreciably the same, whether the iron be or be not magnetised.

The Author next considers the case of iron magnetised in a vacuum. Returning to equation (1), and taking κ and T as independent variables, by analysis similar to the preceding,

$$\frac{d}{d\,T}\left(\frac{d\,Q}{d\,\kappa}\right) - \frac{d}{d\,\kappa}\left(\frac{d\,Q}{d\,T}\right) = \frac{d\,\mu}{d\,T} = \frac{1}{T}\,\frac{d\,Q}{d\,\kappa}.$$

Hence $\left(\frac{d\,\mu}{d\,T}\right)_\kappa$ and $\left(\frac{d\,Q}{d\,\kappa}\right)_T$ have always the same sign. It is known experimentally that in the case of weak magnetisations $\left(\frac{d\,\mu}{d\,T}\right)_\kappa$ is positive, therefore $\left(\frac{d\,Q}{d\,\kappa}\right)_T$ is also positive. It follows then, that if iron be slightly magnetised in a vacuum it is cooled. On the other hand $\left(\frac{d\,\mu}{d\,T}\right)_\kappa$, and consequently also $\left(\frac{dQ}{d\,\kappa}\right)_T$, is negative for strong magnetisations, and therefore in this case magnetisation raises the temperature. The Author has not yet experimentally confirmed this theoretical conclusion, but it is noteworthy that it is closely analogous to the known phenomenon of caoutchouc subjected to small or great pressures.

From the foregoing equation an expression for the relation

between magnetic moment and pressure can readily be deduced. Taking Sir William Thomson's formula for the change of temperature with pressure,

$$d\,Q = \frac{d\,Q}{d\,T}\,d\,T + \frac{d\,Q}{d\,\kappa}\,d\,\kappa = M\,C_\kappa\,d\,T + T\,\frac{d\,\mu}{d\,T}\,d\,\kappa = 0,$$

where M is the mass, and $C\kappa$ the specific heat of the iron for a constant magnetic force κ. Hence

$$\frac{d\,T}{d\,\kappa} = -\frac{T}{M\,C_\kappa}\left(\frac{d\,\mu}{d\,T}\right)_\kappa.$$

But from the Author's experiments,

$$\left(\frac{d\,\mu}{d\,T}\right)_\kappa = C\,\frac{\mu}{\kappa} - B\,\mu,$$

C and B being certain constants determined for the pressure of the atmosphere, hence

$$\frac{d\,T}{d\,\kappa} = -\frac{T}{M\,C_\kappa}\left(C\,\frac{\mu}{\kappa} - B\,\mu\right).$$

If μ is expressed as a function of κ by some empirical formula, the integral of this equation gives the temperature T in terms of κ between the limits o and κ, and consequently the change of temperature due to a magnetic force κ.

The Author next considers in a similar manner the case of a magnetised bar under stress, due to a tension along its axis. Sir W. Thomson and others have tested this experimentally, and concluded that if the magnetisation be weak, an increase in tension produces an increase in magnetic moment, but a diminution if the magnetic moment be near its maximum value. In the first case the change is due to the diminution in the coercive force, while in the second case the effect of change in the molecular magnetism predominates. This is analogous to the effect of changes of temperature.

The Author concludes by pointing out the need for experiments on the following points, as evinced by his researches. 1. The quantitative determination of the change in magnetisation due to an increase of hydrostatic pressure or longitudinal stress. 2. The changes in temperature due to magnetisation in a vacuum. 3. The changes of pressure due to magnetisation; and 4, the determination of the cooling of a bar stretched in a magnetised and unmagnetised state respectively.

E. H.

On the Products of the Combustion of Carbon at different Temperatures. By A. Ledebur.

(Stahl und Eisen, vol. 1882, p. 356.)

When any carbonaceous fuel, whether solid or gaseous, is burnt, the combustion is said to be perfect when the gaseous products contain no further combustible constituents. This condition can only be attained when oxygen is present in excess, and the proportion of such excess required diminishes, as a rule, with the temperature of the fire-place. The preceding statement, generally recognised as accurate, has, in the Author's opinion, given rise to another, which, though current in most text-books and journals, is perfectly incorrect—namely, that high temperatures, such as are produced by combustion with previously heated air, generally favour the production of carbonic acid, and that when carbon is burnt with cold air the product is mainly carbonic oxide. The first part of this conclusion, that concerning the formation of carbonic acid, is only true when oxygen is present in excess; while the second, which deals with the production of carbonic oxide, is entirely inaccurate.

The chemical action of carbon on oxygen being intensified by a high temperature, the Author points out that when sufficient carbon is present to produce carbonic oxide, that gas will naturally be produced, as for the same volume of oxygen twice as much coal will be consumed as when the product is carbonic acid. This necessitates twice as much absorption of heat in the gasification of the carbon, and therefore for equal consumption of oxygen the heat developed, as compared with that when carbonic acid is produced, is as 3 : 5. The larger quantity of coal burnt develops the lesser amount of heat, and when, as a consequence of this or other causes, the temperature falls, a larger initial production of carbonic acid results, whereby heat is more rapidly developed. That the above are not merely unsupported theoretical deductions will be familiar to all who are accustomed to work gas generators, where the gases richest in carbonic oxide are produced with the hottest working. Thus Dr. Stockmann found, when the producers were working cold, 16·56 of carbonic oxide to 12·14 of carbonic acid per cent.; but with hotter working the proportions were 21·73 to 7·41 per cent. The same general result takes place in the hearth of a blast-furnace; the higher the temperature of the blast the more completely do carbonic acid and free oxygen disappear at the twyers; were it otherwise, it would be impossible to account for the increased reduction of silicon and manganese by very hot blast, having regard to the energetic oxidising action of carbonic acid at high temperatures. In blast-furnaces smelting lead ores the conditions are different; carbonic oxide is not required as a reducing agent, and carbonic acid is no drawback, and, as a consequence of the lower temperature prevailing in such furnaces,

carbonic acid is found in notable quantity immediately above the twyers.

After discussing the extreme improbability of the indirect production of carbonic oxide by the reduction of previously formed carbonic acid, the Author describes some experiments upon the combustion of charcoal in air when heated to different temperatures. The apparatus consisted of the following parts:—

1. A gas-holder, containing the air.
2. Washing-bottle, with potash liquor.
3. Chloride of calcium tube.
4. Combustion-tube, containing 5 grams of wood charcoal previously heated to redness, arranged in a furnace.
5. A U-tube, with chloride of calcium.
6. Weighed potash apparatus, No. 1.
7. Second combustion furnace, containing a tube with oxide of copper.
8, 9. Chloride of calcium and potash tubes, similar to Nos. 5 and 6.
10. Chloride of calcium safety-tube.

For heating the charcoal at temperatures below a cherry-red heat a glass combustion-tube heated by gas was used; but for greater heats a porcelain tube and heating by a charcoal and coke fire, with a chimney draught, was necessary. The amount of air consumed in each experiment was approximately the same, namely, 1·1 litre, or 1·422 gram, containing 0·333 gram of oxygen, and the velocity of the current was kept constant by the head of water in the gas-holder.

The experiments were carried out in the following manner:—After removal of the potash apparatus, the oxide of copper in the second tube was heated to redness, the tube containing the charcoal brought to the temperature required, and air was allowed to pass through until the apparatus was filled with gas of uniform composition. The potash-tubes were then introduced, and allowed to remain until the required volume of air was expended, when they were taken out and weighed in the usual manner.

The increase in weight of the first potash-tube gave the direct production of carbonic acid, and from that of the second the proportion of carbonic oxide was calculated. Furthermore, as the oxygen in the first case was derived entirely from the gas-holder, and that in the second to the extent of one-half, the comparison of the calculated quantities of oxygen with that of the air expended gave a sufficiently accurate idea of the amount of oxygen escaping combustion.

The results of the experiments were as follows:—

Temperature of Combustion.	Coal Burned.				Oxygen Used.			
	Total.		Per Cent.		Total.		Per cent.	
	To CO.	To CO_2.	To CO.	To CO_2	Burnt.	Escaping Unburnt.	For Burnt.	Escaping Unburnt.
	Gr.	Gr.			Gr.	Gr.		
Below melting zinc, about 350° C.	0·007	0·025	78·6	21·4	0·076	0·255	33·0	77·0
Melting zinc, about 440° C.	0·032	0·084	72·4	27·6	0·267	0·064	80·6	19·4
Dark-red heat, about 520° C.	0·036	0·091	71·4	28·6	0·291	0·040	87·9	12·1
Commencing cherry-red heat, about 700° C.	0·046	0·077	62·6	37·4	0·266	0·065	80·3	19·7
Yellow heat, about 1,100° C.	0·258	0·003	1·3	98·7	0·353	0·000	100·0	0·0

The Author then compares the results of these experiments with those obtained in practice in ordinary grate-fires, blast-furnaces, and Bessemer converters, and shows them to be substantially in accordance.

H. B.

On Currents produced by Nitrates in Igneous Fusion, in Contact with red-hot Carbon. By — Brard.

(Comptes rendus de l'Académie des Sciences, Paris, vol. xcv., 1882, p. 890.)

A. C. Becquerel, in 1855, was the first to note this remarkable property of fused nitrates. The Author verified in the first instance Becquerel's experiment, by plunging into a capsule containing a bath of nitrate in fusion, a stick of red-hot carbon, when an energetic current was obtained, passing from the bath to the carbon in the external circuit. Various kinds of carbon were used, and it was found the current gradually weakened owing to a hard and compact deposit of salt, which, interposing itself between the nitrate and the carbon, stopped the chemical action.

The fused nitrates become very fluid, and acquire the property of greasy bodies of wetting at a distance heated substances with which they are in contact. A drop of these salts rapidly covers a large surface of a heated plate of metal, and, thanks to this property, the liquid rises up these bodies by capillary attraction to a height of even 30 millimetres (1·18 inch). Hence a current can be obtained by heating to a red heat the end of the carbon not in the fused nitrate so long as it is of short length. The Author

also finds that a current may be obtained, even if the carbon does not dip into the nitrate; it is simply necessary to place upon heated carbon a metal capsule containing the fused nitrate, the result being due to the circumstance already stated, that the nitrates have the power of suffusing the heating-surfaces with which they are in contact. In a few moments it is found that the interior surface of the capsule, situated above the level of the nitrate, gradually becomes wetted, and, after gaining the edge of the capsule, flows over its surface. Indeed, it is not necessary, in order to obtain a current, to place the nitrate in contact with the carbon, for a metal capsule, containing the salt in fusion, freely suspended above a source of heat, gives rise to a current passing from the nitrate to the exterior surface of the capsule. A continuous permanent current of 6 to 7 milliamperes was obtained by placing above a Bunsen flame a capsule covered with a piece of asbestos paper, itself covered with plumbago and metallic plate. The best results are obtained by placing the capsule as near as possible to the upper portion of the flame. The nitrates employed melt at about 200° C., and do not decompose below a temperature of 1000° C. Up to this point the metal of the capsule is not attacked, but the contrary effect of protecting the surface from oxidising by heat, or at least considerably retarding it, seems to result.

E. F. B.

On the Luminosity of Flames. By Dr. Werner Siemens.

(Sitzungsberichte der Königlich preussischen Akademie der Wissenschaften, 1882, p. 961.)

The luminous rays emitted by a gas in the process of combustion are due in general to a secondary effect, and result from the incandescence of solid or fluid particles suspended in the flame. A gas, which neither contains nor, in burning, produces such particles, emits a faint light of a colour depending on its own nature. Experiments conducted, at the Author's request, by his brother, Frederick Siemens, at the latter's glass-works in Dresden, as well as in the laboratory by Dr. Frölich, showed that gases heated to the melting-point of steel (1,500° to 2,000° Centigrade), and from which all dust was excluded, emitted absolutely no luminous rays. A regenerative furnace was provided with a series of screens, so that its contents could be observed when shut off from all extraneous light, and when as high a temperature as its construction would allow of was reached, the admission of further hot gas was stopped, and observations then taken with the results above given. The contents of the furnace would consist of oxygen, nitrogen, carbonic acid gas, aqueous vapour, and the products of previous combustion. In the laboratory the field of view was seldom absolutely dark, but the difficulty of keeping the flame absolutely free from dust, and the extreme sensitiveness of the

observer's eye, after long confinement in total darkness, would readily account for such discrepancy.

The Author conjectured that the emission of thermal rays might also depend on the same secondary effects, but soon convinced himself that such was not the case; finding, indeed, that with a thermopile directed towards an argand flame, or the heated products above it where the direct rays from the flame itself were screened off, there was little or no variation in its indications. This was, however, probably due to the sensitiveness of the thermopile and the smallness of the aperture necessarily used, as a marked increase was observed in its indications when a piece of platinum wire was inserted in a non-luminous flame. The Author's conclusion is that the luminosity of the flame, depending as it does within such sharply-defined limits on chemical action, is due to the vibration set up in the "ether-mantles," which he supposes to surround the molecules, by the alteration produced by the combination of those molecules in the process of combustion, and adduces as corroborative evidence the chemical action accompanied by faint luminosity set up by the passage of the electric spark in his ozone apparatus; as well as the similarity in colour and intensity of the light emitted by a gas in Geissler tubes and in flames.

F. J.

On the Electrical Experiments to determine the Location of the Bullet in the Body of the late President Garfield, and on a successful form of Induction-Balance for the Painless Detection of Metallic Masses in the Human Body.

By Alexander Graham Bell.

(American Journal of Science, vol. xxv., 1883, p. 22.)

Though the primary object, for which the extensive series of experiments here described was undertaken, was not attained, and, owing to the position of the bullet, as a post-mortem examination subsequently proved, even unobtainable by the use of any of the experimental apparatus devised by the Author, still the researches led to the conclusion—corroborated by actual trial on the living object—that in certain cases, where a bullet is not more than a few inches from the surface, its exact position can be determined. The theoretical basis of these experiments is the alteration in the equipotential surfaces of an induced electrical field, which is caused by the presence of conductive particles, and the practical execution is effected by sending an interrupted current through a primary coil, and observing its action on a secondary coil by means of a telephone in the circuit of the latter; the position of the secondary coil is adjusted to silence, and the effect due to the introduction of a bullet in its neighbourhood noted.

The Author's attention was naturally directed in the first instance to determine the best form which should be given to the coils, so as to obtain the greatest hearing distance. After a few preliminary experiments with two flat spiral coils, similar to those proposed by the Author for eliminating disturbance on telephonic circuits, the method of Professor Hughes' induction-balance was adopted. In the arrangement of this apparatus it was experimentally determined that, to obtain the best effect, the primary coil should be larger in diameter than the secondary, and the plane of the latter project considerably beyond the plane of the former; thus the dimensions of the Author's ultimate form of exploring coils were, for the primary, 7 centimetres (2·8 inches) diameter, and 2·4 centimetres (0·96 inch) deep, with a resistance of 2 ohms; and for the secondary, 2·3 centimetres (0·92 inch) diameter, and 8 millimetres (0·32 inch) deep, with a resistance of 75 ohms, the face of the latter projecting 4 millimetres (0·16 inch) beyond that of the former, the fixed balancing-coils being made as nearly as possible similar; the maximum hearing distance for a bullet was, however, not more than 4·2 centimetres (1·68 inch).

On the 26th July, 1881, the first experiment was made on the President's person, but proved unsuccessful, as no preliminary balance could be obtained; this was subsequently traced to an error in the introduction of a condenser into the wrong part of the circuit.

Attention was again directed to the form of balancing coils, and, as increasing their resistance was found to diminish their sensitiveness, recourse was had to the original form of two spiral coils, mounted eccentrically one over the other and adjusted to silence; with such a combination of two coils, each 10 centimetres (4 inches) diameter and 1 centimetre (0·4 inch) thick, and by using a powerful battery in conjunction with a condenser, a hearing-distance of as much as 13 centimetres (5·2 inches) was obtained. A curious phenomenon was remarked during this series of experiments, and traced to the introduction of the condenser, namely, that by it a partial of the fundamental tone due to the vibration of the contact-maker was plainly detected, and that the actual partial reinforced depended on the capacity of the condenser.

On communicating this satisfactory result to the President's physicians, the Author was requested to make another personal trial without delay; the balancing and exploring coils were therefore hurriedly arranged in a portable form, but no balance at all was obtainable, and this unsatisfactory result was found to be due to an extremely slight abrasion in the silk covering of the external layer of one of the coils. The necessity for perfect insulation between the separate convolutions of a coil is thus proved to be an absolute requirement in all similar research, this fact being also established by special experiments on this point. These coils being again put together after repair, a perfect balance was now obtained, but owing to the thin walls of the case, in which they were mounted, yielding to the pressure of the coils during movement, pulsations

of sound were observed in the telephone, which caused great difficulty in the exact localisation of any reinforcement of sound; however, in the actual trial on the President's person, a probable position was determined, and at the same time a feeble sound was observed over an extensive area, subsequently traced to the wire mattress of the President's bed. Another set of coils were made of the same type, and solidly embedded in paraffin enclosed in an ebonite case, the final adjustment being secured by two auxiliary coils introduced in the respective circuits, and very good results were obtained with this combination by localising in two patients the position of bullets which they were known to carry in their persons; in one case the accurate position was not known, but, as revealed by this electrical method, was supported by medical evidence from previous behaviour of the wound. A modification of the arrangement, subsequently proposed by Mr. Sumner Tainter, the Author's able coadjutor in these experiments, admits the use of a single exploring-coil, and thus eliminates the evil effects resulting from movement of the double coils in disturbance of the balance. It is unfortunate, the Author remarks, for the success of this method, that bullets are made of lead, which is such a bad conductor; were silver or iron used, no difficulty would be experienced in determining their position in any part of the human body. A method of verifying the position is proposed, which consists in probing with a steel needle connected with a telephone, the circuit being completed by a plate pressed against the surface of the skin, the galvanic action set up by the contact of the two metals on the needle meeting any metallic obstruction would cause a decisive click to be heard in the telephone.

F. J.

Absolute Measurement by means of Bifilar Suspension, especially as applied to two Methods for the Determination of the Intensity of the Horizontal Component of the Earth's Magnetism without Time-Observations. By F. KOHLRAUSCH.

(Wiedemann's Annalen, New Series, vol. xvii., 1882, p. 737.)

This mode of suspension seems to have been much neglected, owing, probably, to the supposition of difficulty in determining the constants with a sufficient degree of accuracy. The Author maintains, however, that it possesses considerable advantages over the unifilar mode, especially in the reduction of the time required for the observations, and the diminished difficulties of manipulation; and contends that results thus obtained would be at least as accurate, if all the objections for each system are taken into account. The expression for the directive force of such suspension is fully considered, regard being had to the corrections required for rigidity, elasticity and inequality of tension in the fibres. Let

m be the mass of the suspended body, to which is added half that of the fibres, d_1 d_2 the horizontal distance between their upper and lower ends, and E, their modulus of elasticity. The fibres are supposed to be nearly equal in length, and the correction for rigidity $\rho^2 \sqrt{\frac{2\pi E}{m}}$, where ρ is the semidiameter of the fibre, is to be subtracted from the measured mean value; let this reduced length be l, then the directive force of the system which, multiplied by the sine of the angle of deflection, gives the force of the deflecting couple, is given by the expression

$$g\,m\,\frac{d_1\,d_2}{4\,l} + \frac{2\,\pi\,\rho^4\,E\,g}{l},$$

where g is the accelerating force of gravity.

In the determination of the data for the practical execution of the method, the weight of the body can be ascertained both before and after attachment to the suspension, and in this way a ready means of controlling the value at any subsequent period, without severing the attachment, presents itself. Equality in tension of the two fibres is detected by equivalence in the time of vibration resulting from lateral percussion, and from the fact that the vertical line passing centrally between the two fibres must cut the centre of gravity. The measurement of length and distance apart can be determined by any ordinary micrometric method, as well as any elongation due to the load. The Author has applied this system of suspension to two methods for the determination of the horizontal intensity of the earth's magnetism, depending on the action on a magnetic needle of a suspended coil in one case, and in the other of a magnet, resulting from its deflection, due to the terrestrial magnetism. The details of the instruments, illustrated by plates, and the operation and results of the experiments by the two methods, are given in full; and the approximation of the final value in the two cases confirms the Author's conclusions above mentioned as to the advantages of his proposed methods, and of bifilar suspension.

F. J.

The Magnetic Station at the Park St. Maur Observatory.

By T. Moureaux.

(La Nature, Nos. 511 and 513, pp. 246 and 276, March 1883.)

This station was built last summer by Mr. Mascart, the Director of the Paris Meteorological Station, and consists of a pavilion 23 feet long by 16½ wide, the short side being in the geographical meridian; this contains two vaulted caves, each ventilated on three sides by air-holes, which in the eastern cave are darkened, without however excluding the necessary ventilation. The instruments

used in each cave for determining the magnetic direction and intensity are three, viz., the declinometer, the bifilar, and the magnetic balance, all mounted on masonry pillars about 6½ feet apart, those in the western cave being read directly by telescopes, while the indications of those in the eastern cave are automatically recorded by photography. To obtain a continuous record of the latter, Mr. Mascart has invented a magnetometer, which, while in no respect less accurate than the Kew one, offers the following advantages:—

1. Is considerably less costly;
2. Requires a smaller magnetic cave;
3. Employs only one lighthouse for the three instruments;
4. Registers all the elements on the same sheet of paper.

It consists of a case divided in two throughout by a wooden partition; the back contains the clockworks, while the front forms a dark chamber which contains the photographic slide moving in a grooved frame, which by means of a rack and toothed wheel, driven by the clock, completes a descent behind a window in the case once in every twenty-four hours. The clock-pendulum oscillates in a plane parallel to the magnetic meridian. The light is supplied by a small gazogene lamp, which, well regulated, will burn steadily for thirty-six hours; by replenishing it at a fixed hour daily, a constant illumination is secured. The focus of the lamp is centred in a lantern fixed to the clock-case, and fitted on each of its three free sides with a metal frame carrying a field lens and a vertical slit, which can be narrowed at will. One of these slits sends a ray to the declinometer, a second sends to the bifilar, and a third to the balance; and these are so arranged that the luminous images, after reflection on the fixed and movable mirrors of each instrument, are returned clearly upon the sensitised paper, one-third of the breadth of this paper being reserved for the indications of each instrument. Six traces are thus obtained upon the paper, three being the fiducial lines of each of the elements, and three the curves of their variations. The deviation of a curve to the right of the fiducial line for each element, is proportional to the angle between the mirrors. The hour is also recorded upon the paper, the clock-movement being arranged so that the grooved frame falls exactly 1 centimetre (0·4 inch) an hour, the total length of the daily curves being thus 24 centimetres (9⅓ inches). The paper is pressed in the slide between two sheets of glass, one of which (the one on which the sensitised side rests) is transparent, and bears twenty-five horizontal studs, each 0·4 inch apart; these studs appear in turn before the window in front of the photographic slide, and, by intercepting the light, cause breaks in the lines formed on the paper. The exact time at which each sheet is inserted is written upon it afterwards, as also the date, but all other inscriptions are made photographically; the slide is remounted, and the lamps renewed daily at mid-day.

After the photographic images have been developed and fixed, it only remains to reduce the curves to their numerical values;

the results shown by the automatic recorder are finally checked by the direct readings of the instruments in the western cave of the observatory.

E. H. C.

The Temperature-Coefficient of Naudet's Aneroid. By F. Klein.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereins, 1882, p. 212.)

The barometer-height reduced to 0°, B_0, given by a Naudet's aneroid reading, A, is found from the equation

$$B_0 = a + b\,(760 - A) - c\,t,$$

where t denotes the inner temperature of the aneroid, and a, b, c, the constants to be determined for each instrument by comparison with a standard barometer. The object of this Paper is to ascertain whether c (the temperature coefficient) is really constant, or whether it possibly varies

(*a*) With the date of the observation.
(*b*) With the air-pressure.

(*a*) Major H. Hartl, the Director for Geodesy in the Military Geographical Institute, has already published his researches on this subject. By fifteen thousand observations, made with eighty-three aneroids, between 1869–1881 at Vienna, he found that for most of Naudet's aneroids c is unchangeable with the date, only two having shown a gradual increase of this coefficient. Of the other eighty-one aneroids, twenty had a temperature coefficient of 0·15, between five and eight had it varying between 0·11 and 0·17, while larger and smaller values of c (0·24 – 0·03) were very rare. He also found that when the mean error of c was not more than ± 0·014, at least thirty to forty careful observations must be uniformly distributed over temperatures of from 0° to 30°.

(*b*) Hartl further investigated, while engaged in a triangulation in 1875, whether c depends on the pressure; no artificial means were necessary to get the requisite lower temperatures; but those up to over 40° Centigrade he obtained by exposing the aneroids to the sun in blackened wood cases until the inner thermometers were stationary. From observations taken during 1875–1880, the Author shows that the temperature-coefficients of five aneroids *were smaller on a reduction of the pressure.*

Hartl concludes that in practice it does not at all suffice to observe a Naudet's aneroid at only small fluctuations of pressure at one and the same place, but that determinations for c must be made at very varying pressures in order to construct a Table with *two entries*, from which the actual correction for the temperature noted on the inner thermometer, and for the barometer-height read on the aneroid scale, may be taken out.

E. H. C.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1882–83.—Part II.

END OF VOL. LXXII.

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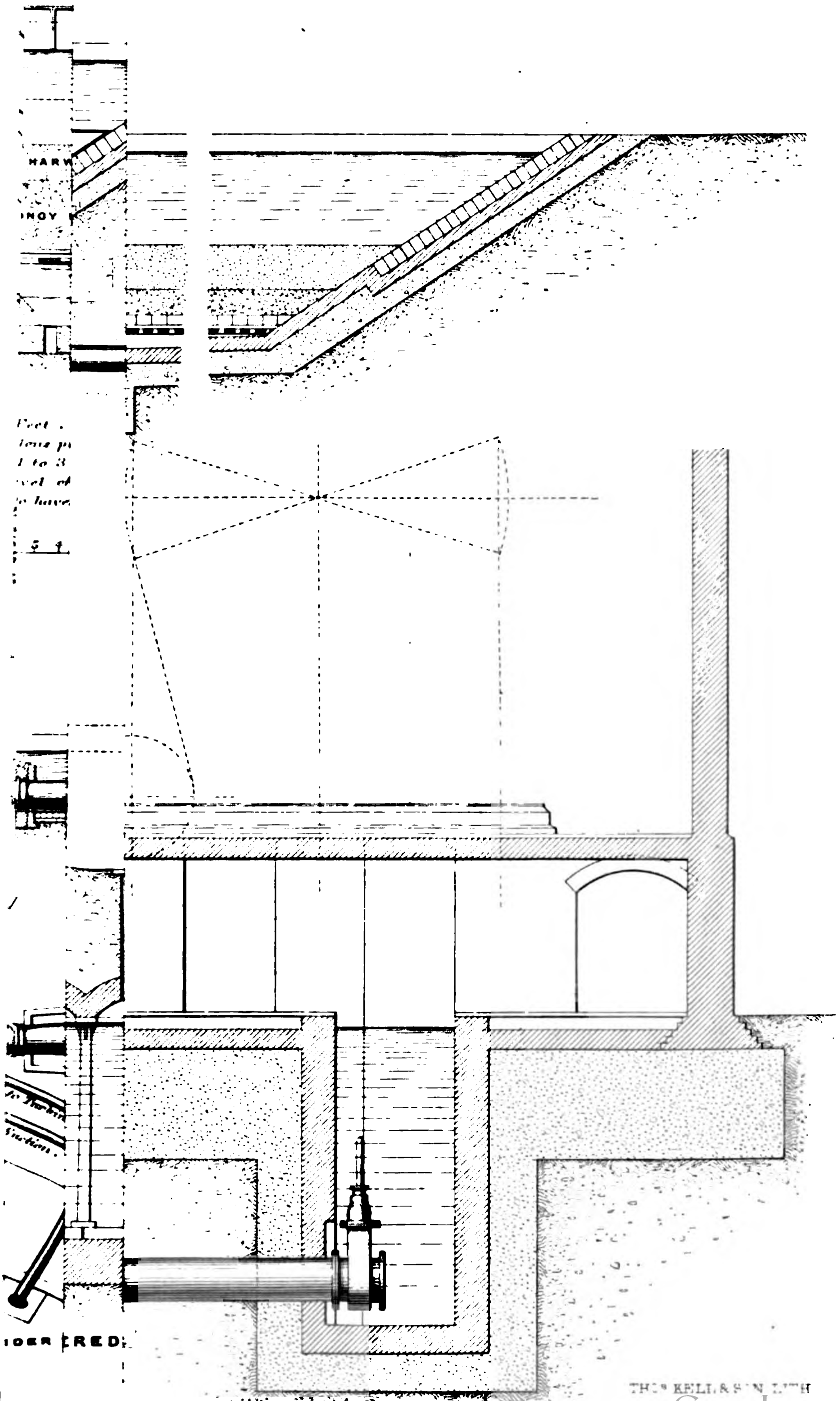
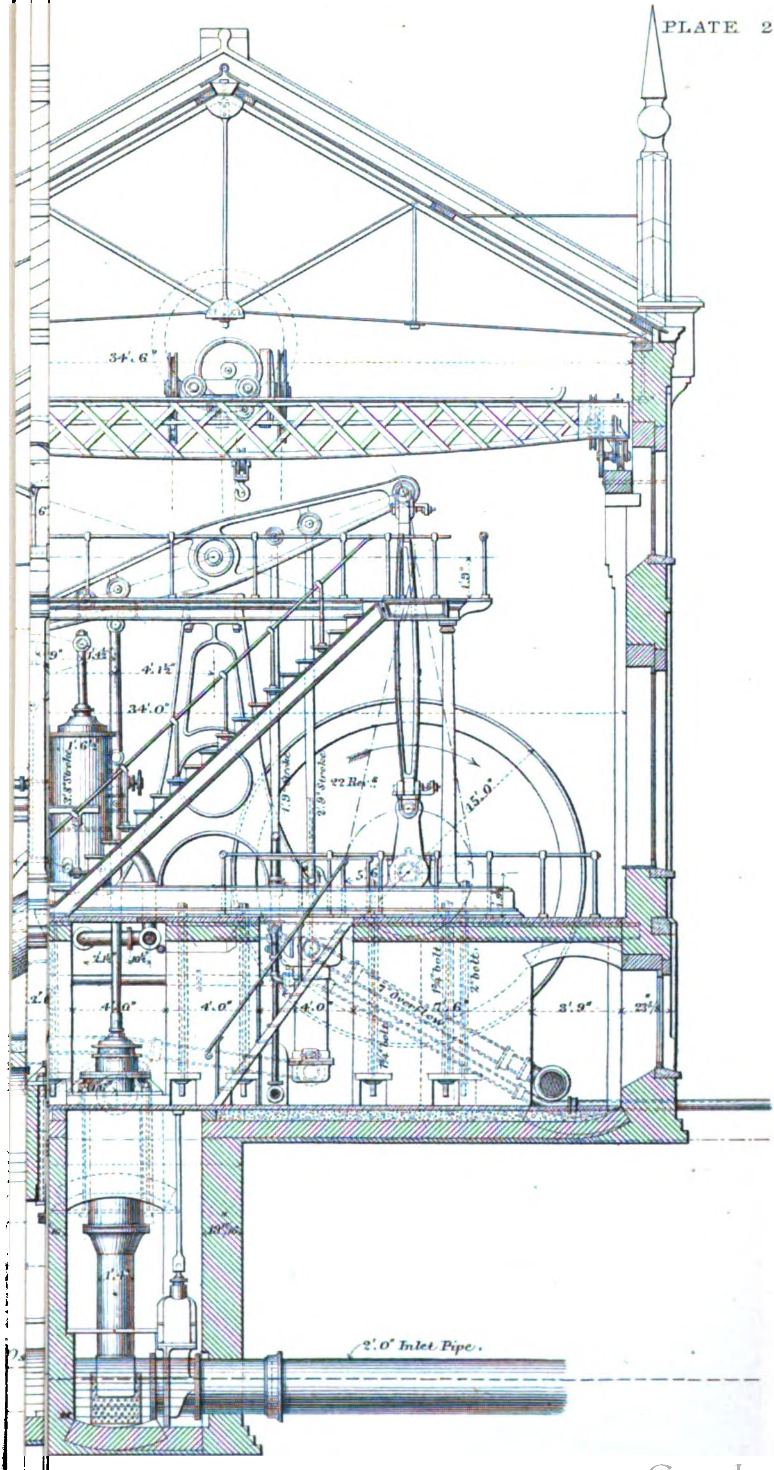


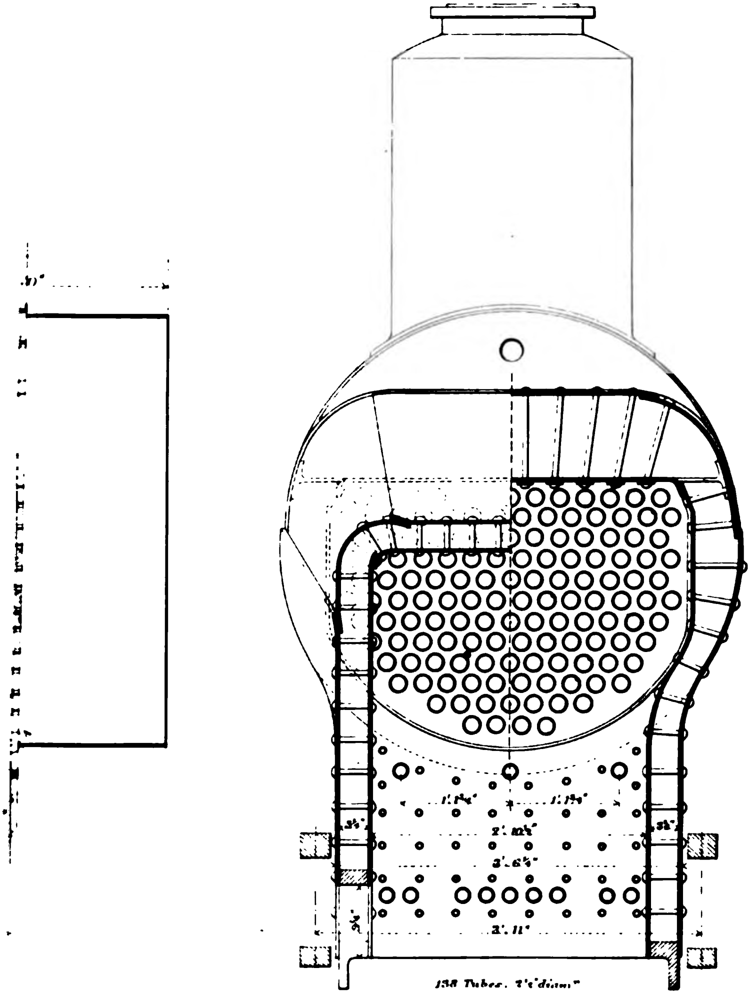
THOS KELL & SON, LITH
40 KING St COVENT GARDEN

PLATE 2.



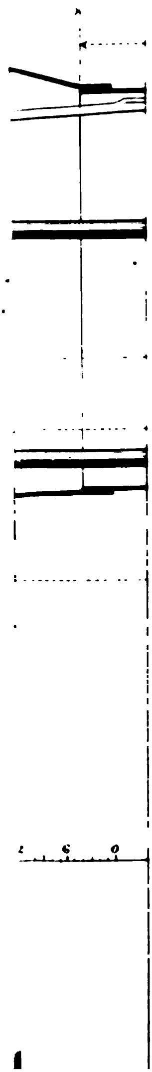
THOS KELL & SON. LITH 40 KING ST COVENT GARDEN

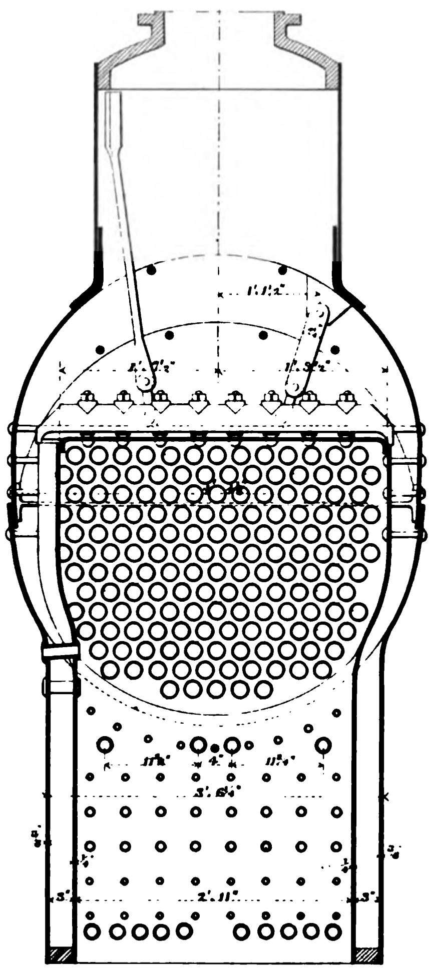
PLATE. 8.



THE FELL & ... LITH 42 KING ST COVENT GARDEN

PLATE F.





153 Tubes

Diameter of Tubes not given
but measures about 2⅛ or 2¼

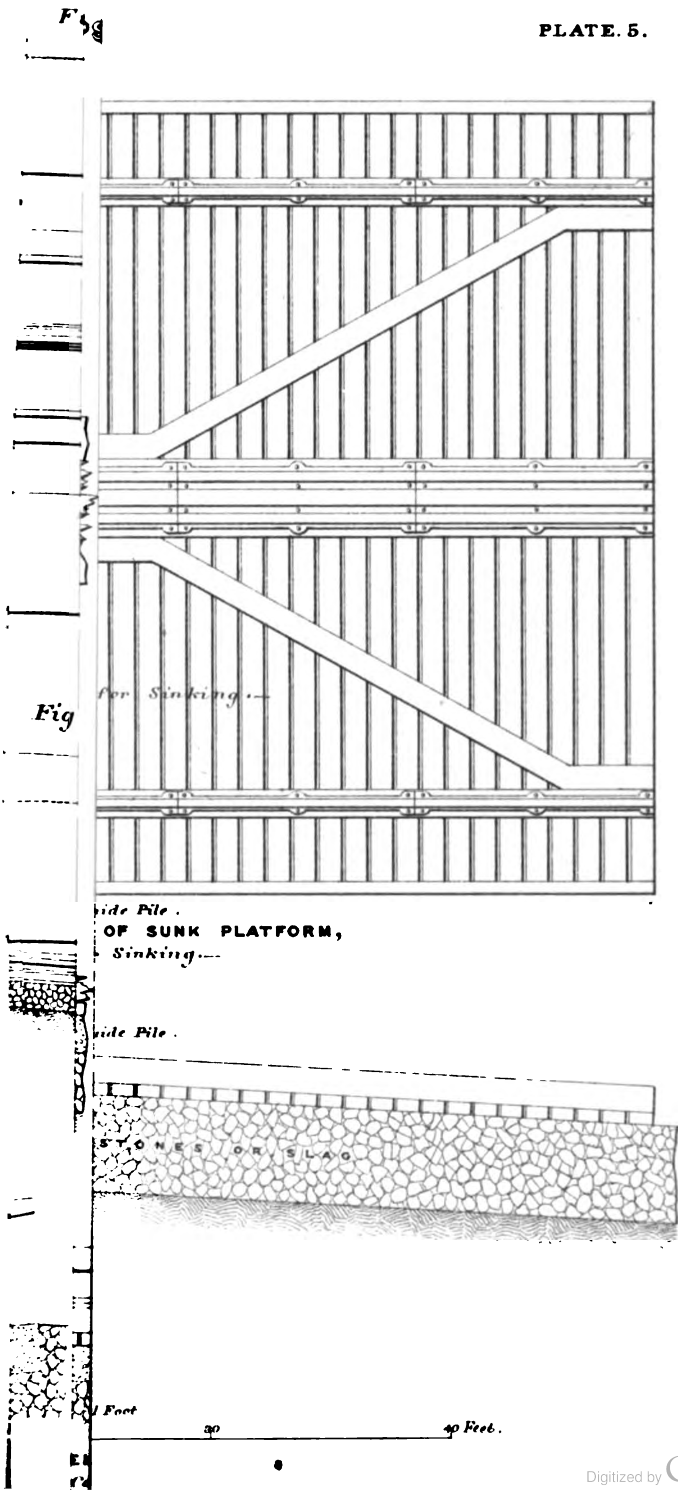
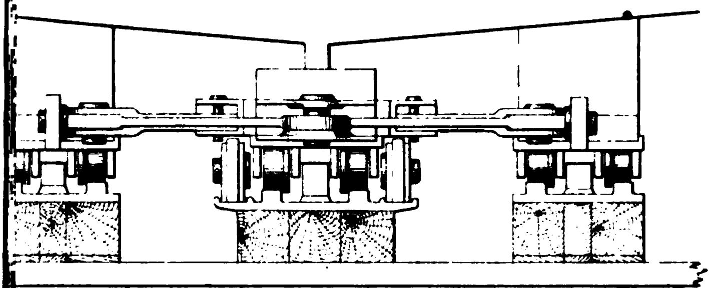


Fig
Fig
for Sinking.—
ide Pile.
OF SUNK PLATFORM,
Sinking.—
ide Pile.
STONES OR SLAG
1 Foot
30
40 Feet.

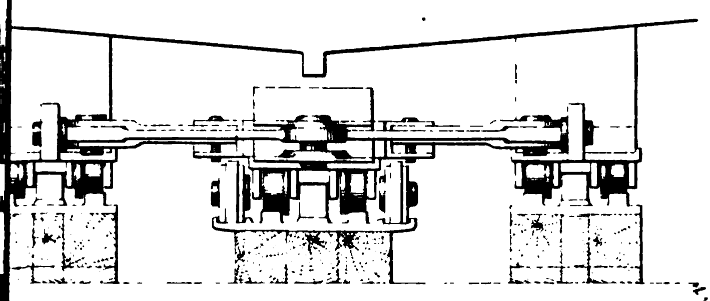
PLATE. 6.

Fig: 10.



EW OF CRADLES, 50 FEET FROM TOP OF SLIPWAY, SHOWING VESSEL RESTING.

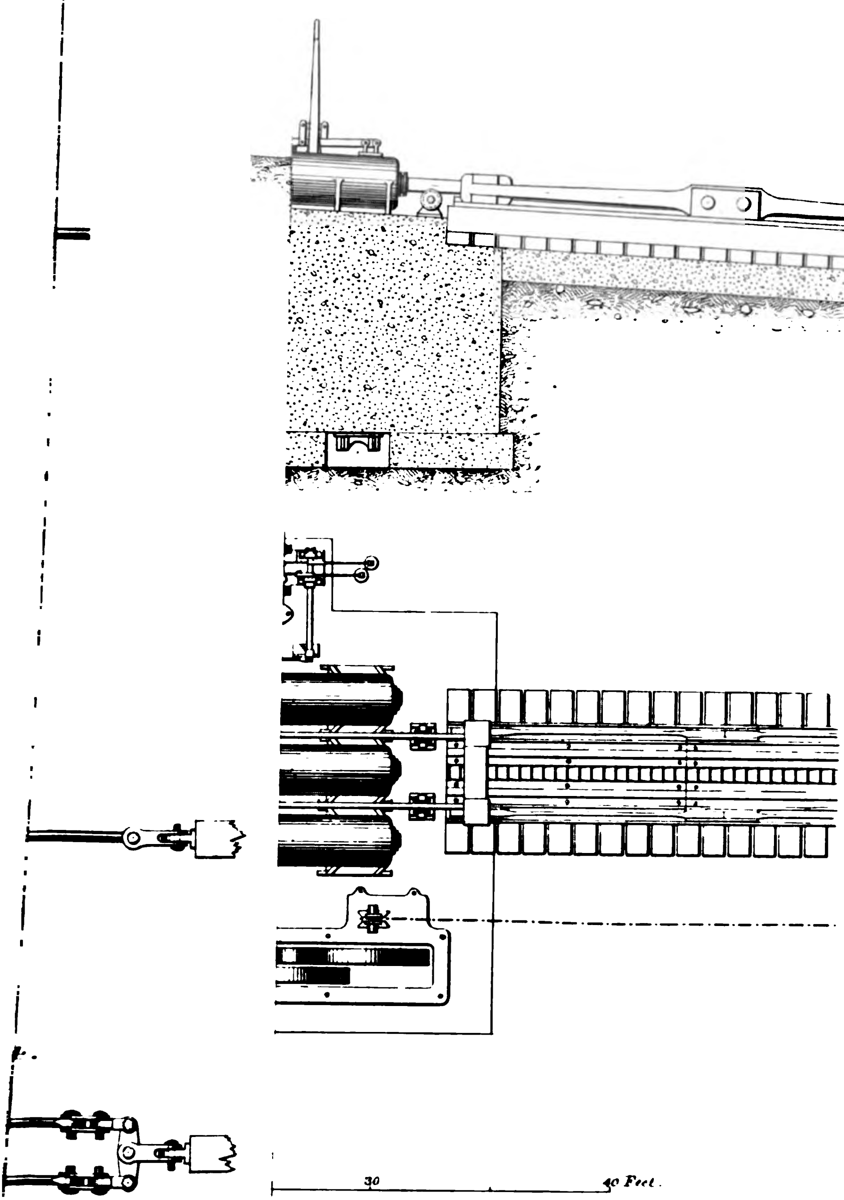
Fig: 11.



END VIEW SHOWING VESSEL LIFTED FROM MAIN CRADLE.

Scale 1/4 Inch = 1 Foot.

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet



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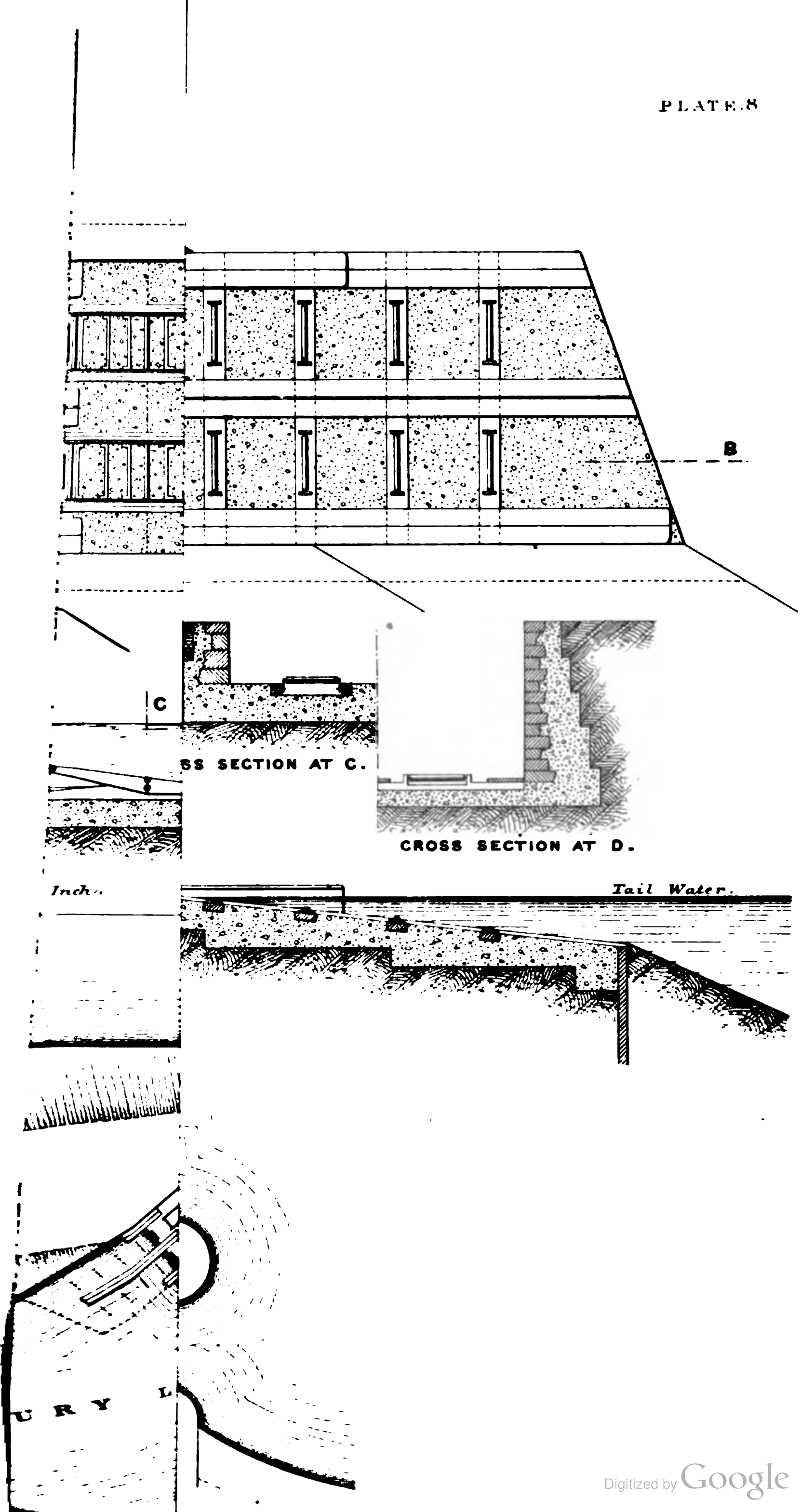
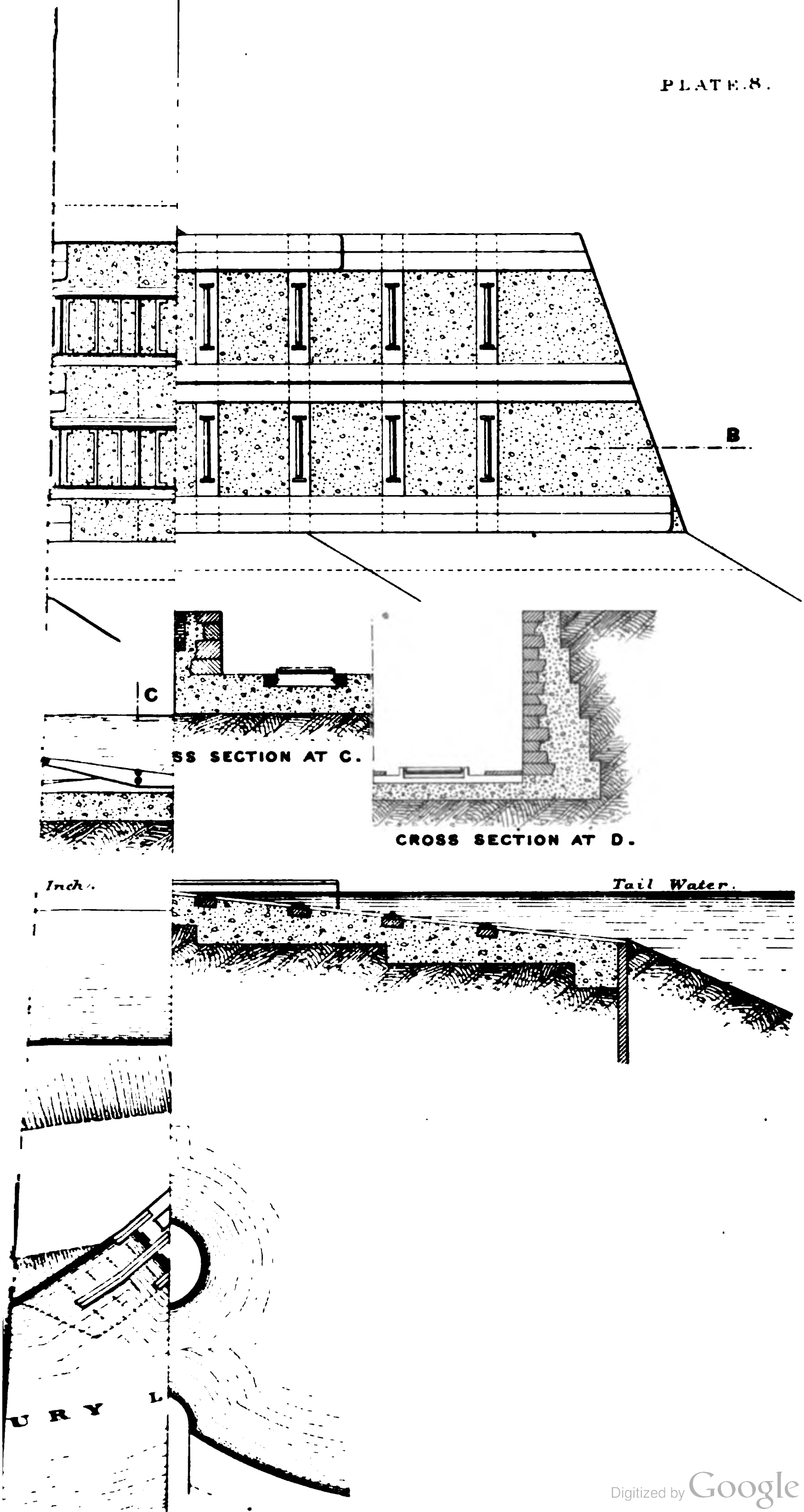


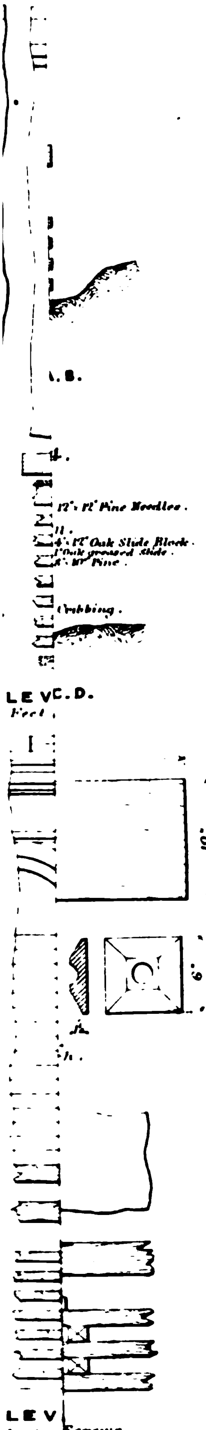
THOS KELL & SON, LITH 40 KING ST COVENT GARDEN

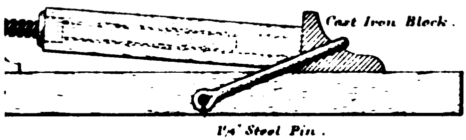
PLATE 8.

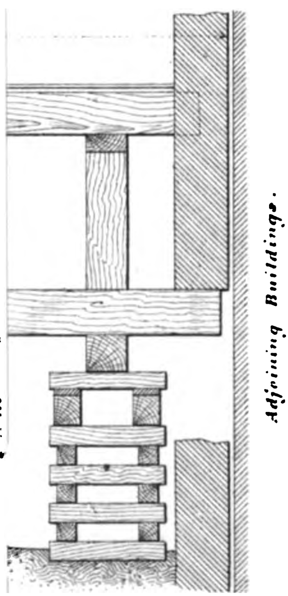


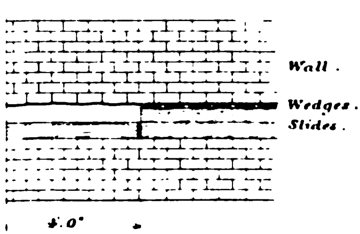
THOS KELL & SON LITH 40 KING ST COVENT GARDEN

PLATE 9.


12"x12" Pine Needles.
4"x12" Oak Slide Block.
Cribbing.
10"
6"

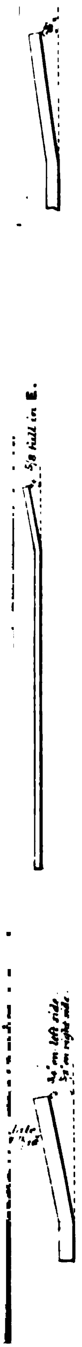

Cast Iron Block.
1¼" Steel Pin.


Adjoining Buildings.


Wall.
Wedges.
Slides.
4.0"

MEN

PLATE 10.



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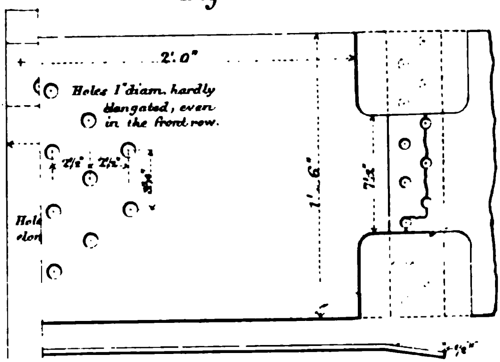
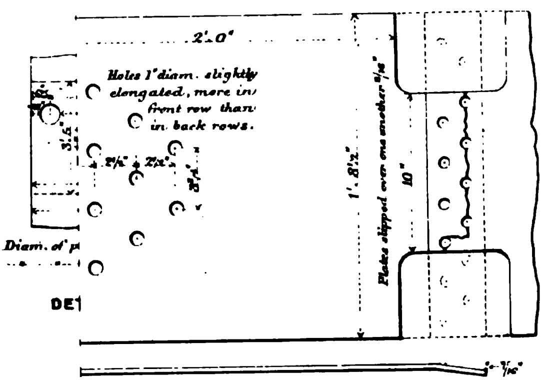


FORM OF SPECIMENS A & B.

showing fracture of both. — 5/16" plates.

PARTIC

Fig: 11.



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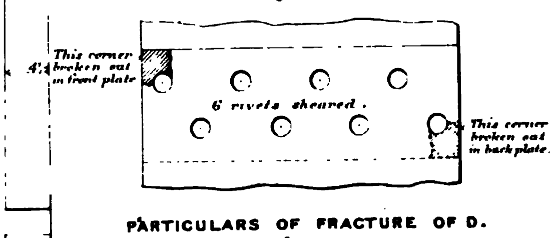
FORM OF SPECIMENS C & D.

showing fracture of C. — 5/16" plates.

Fig: 12.



PARTICULARS OF FRACTURE OF D.

5/16" plates.

TH. KELL & SON LITH 40 KING ST COVENT GARDEN